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Destruction Technologies for Polychlorinated Biphenyls (PCBs)

Canada

Economic and Technical Review
Report EPS 3-EC-83-1

Environmental Impact Control Directorate

ENVIRONMENTAL PROTECTION SERVICE REPORT SERIES

Economic and Technical Review Reports relate to state-of-the-art reviews, library surveys, industrial inventories, and their associated recommendations where no experimental work is involved. These reports will either be undertaken by an outside agency or by the staff of the Environmental Protection Service.

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DESTRUCTION TECHNOLOGIES FOR POLYCHLORINATED BIPHENYLS (PCBs)

Waste Management Branch
Environmental Impact Control Directorate
Environmental Protection Service
Environment Canada

based on a report to the Waste Management Branch

by

M.M. Dillon Ltd.
Consulting Engineers and Planners
Toronto, Ontario
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ABSTRACT

Data concerning efficient and acceptable methods for the destruction of PCBs in Canada are presented in this report. The information on the technologies was gathered from numerous sources to provide background information for future assessment or to assist in a selection process. The technologies reviewed fall into four categories: conventional incineration, novel incineration, chemical processes and physical/chemical processes.

RÉSUMÉ

Le présent rapport expose les données portant sur les méthodes efficaces et acceptables de destruction des PCB au Canada. Ces renseignements proviennent de diverses sources et constituent les données de base sur lesquelles on pourrait fonder des évaluations futures ou dont on pourrait se servir pour faciliter un éventuel processus de sélection. Les techniques en question se regroupent en quatre catégories: procédés d'incinération classique, nouveaux procédés d'incinération, procédés chimiques, procédés physico-chimiques.

FOREWORD

Although this publication is largely based on a report dealing with PCB Destruction Technology done under contract by M.M. Dillon Limited in February 1982, a significant amount of data was supplied by various equipment manufacturers. Basically it is a "review" done not to assess current technology but rather to provide factual data to help others assess the present state of the art and eventually recommend acceptable, cost efficient solutions for the destruction of PCBs in Canada.

The review was done at this time because there is considerable activity in the field of technological development of hazardous waste destruction processes - note that more than eighty technologies are currently listed for the destruction of PCBs - and because there is a growing need to take action.

The need is growing because PCBs and PCB-containing wastes are presently not being destroyed but only stockpiled in ever increasing quantities in various locations throughout Canada since destruction facilities are yet to be built. A number of significant spills have occured in Canada. Several new disposal processes are now emerging from research centres competing with conventional high temperature incineration. Although two destruction facilities (rotary kilns) were recently open in the USA the border can be closed at anytime to the entry of PCBs and other material. Federal guidelines for the management of PCB Wastes will be soon published by Environment Canada.

We wish to make it clear that this first phase effort, which will be followed by others, has not been prepared to assist us in developing an advocacy position, nor has any attempt been made to compare one process, or system, with another.

The data in this publication has been gathered directly from the M.M. Dillon Limited report and from manufacturers submissions. This data has not undergone rigorous technical review by Environmental Impact Control Directorate and the content of the report does not necessarily reflect the views and policies of Environment Canada.

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POLYCHLORINATED BIPHENYL (PCB) DESTRUCTION TECHNOLOGY

A COMPREHENSIVE REVIEW OF ALL CURRENT METHODS OF TREATMENT/ DESTRUCTION OF PCB WASTES IN NORTH AMERICA

1 INTRODUCTION

In this decade, much public and scientific concern has been expressed about the presence of polychlorinated biphenyls (PCBs) in our environment and in our food. Usually the major concern is the long-term cumulative effects of exposure to PCBs on human health and on many forms of life on earth, and not the immediate lethal or overt effects associated with short-term exposure. Based on these scientific warnings, regulators in both Canada and the United-States enacted legislation to regulate PCBs. In 1977, PCBs production was banned in both countries and strict controls were implemented. As a result of these measures PCBs and PCB Wastes, instead of accumulating in the environment, began to accumulate in various forms of temporary containment awaiting destruction.

The purpose of the following technical review is to show that numerous methods of treatment/destruction of PCB Wastes, in various forms of development are available in Canada and the United States.

2 SOURCES OF INFORMATION

A perfunctory literature search was performed initially by Dillon but was found to be relatively unfruitful, since the type of technological development for PCB destruction is usually a mixture of:

- application of conventional technology involving a key innovation that is kept secret;
- conceptual studies that are the subject of interim reports between developers and funding agencies; and
- integrated business ventures with a vested interest in maintaining a competitive advantage through non-disclosure.

In short the potential for high profits for companies that gain approval to destroy PCBs has attracted many individuals who are promoting their processes without the type of objectivity that one expects in referred literature. As a result very little useful data show up in the usual technical literature. The more valuable sources of information were publications such as: Hazardous Materials Intelligence Report, and Eco/log Week.

Another major source was the United States Environmental Protection Agency (EPA) since their highly structured permitting process for PCB destruction is reviewed region by region (EPA regions I through X) on a bi-monthly basis. Each technology seeking EPA approval is listed along with current status and a local regional person to contact for additional information.

Through this EPA listing and personal knowledge of the field the various organizations were contacted by Dillon and information was requested. Once agreement to participate in the study was secured, a confirming letter was sent along with a copy of the terms of reference for the study. The contacts were encouraged to review the requirements of the terms of reference and respond as they saw fit.

Three major studies performed in the United States supplemented the list of contacts. These were (EPRI, 1979; Ackerman et al., 1981 and Sworzyn and Ackerman, 1981).

These reports, while useful in ensuring coverage of the field up to 1980, had a drawback in that they selectively suggested potential applications of known, off-the-shelf units. Upon checking, in several instances, the technology had not been applied to PCB destruction.

Data received from companies was uneven. Some provided comprehensive data and that is reflected in the detail of their write-up. Others provided sketchy information or were at such an early stage of development that the process description has been included in a brief overview manner.

Costing data was arrived at independently of company pricing suggestions and was current in February 1982. For the purpose of this study it was important that comparable capital and operating costs be put forward. Costs provided by promoters of a technology often included a local advantage that would not always apply to an individual contemplating the use of that technology at his own location. This does not mean that similar advantage might not be realized in Canada, but a comparison could not be made on any basis other than an independent assessment.

Care must be exercised in using the costing data. The PCB feed rate used in arriving at costing data could consume an individual's PCB waste stockpile in a relatively short period of time. Consideration must, therefore, be given to under utilizing a process or scaling it down and losing the economy of its scale. For costing purposes PCB liquid waste was assumed to be 20% PCB in oil and solid waste was assumed to contain 10% PCB.

3 CONTROLS AND SOLUTIONS

In this section the need for the safe destruction of the vast quantities of PCBs currently in use and in storage is examined. The environmental and health problems are summarized and a brief historical background is provided for the Canadian experience. Finally the actual size of the current PCB problem in Canada is given.

3.1 Environmental and Health Problems

Certain synthetic substances included in the class collectively known as chlorinated organic compounds, and used extensively in a number of industries today, are the subject of growing concern as environmental pollutants because of both their persistence and their wide dispersal. Prominent among them are polychlorinated biphenyls (PCBs). Because of this excessive persistence in the environment and the harmful effects of long-time, low-level exposure, PCB have become a global environmental problem.

For many years, isolated reports of the toxic effects of PCB in the industrial medical literature caused little general interest. More recently, public concern was aroused by a number of incidents, the most serious being the contamination of rice oil in Japan in 1969 which affected 1 000 people.

3.2 Production, Distribution and Historic Disposal of PCBs

All PCBs produced in North America were manufactured by a single company called Monsanto. The production and distribution of PCB including disposal is shown in detail in Table 1. The export figures include exports to Canada which amounted to 22 000 tonnes between 1954 and 1975 period when most of this commercial activity took place. Presently there remains approximately 16 000 tonnes in use and in storage in Canada, as explained in Section 3.3

In the past practices used in the United States and Canada, for the disposal of PCBs were normal, accepted industrial practices. PCBs were incinerated as a manufacturing waste (probably to recover the chlorine content) or as a component of waste oil burned for its heat content or even as a component of ordinary solid waste. PCBs were sent to landfills and other municipal disposal facilities as part of the waste from capacitor and transformer manufacturing processes or as obsolete electrical equipment or associated with paper, plastics or oily wastes.

TABLE 1 AMERICAN PRODUCTION AND DISTRIBUTION OF PCBs*

			(tonnes x 10^3)	
Use: (Total)	Transformers		150	
	Capacitors		290	
	Plasticisers		52	570 originally used in the USA prior to controls implementation
	Hydraulics and Lubricants		36	
	Carbonless Copy Paper		20	
	Misc. Industrial		12	
	Heat transfer		9	
	Petroleum additives		1	
Use: (Present) (1975)	Transformers		136	
	capacitors		205	345 in use following implementation of regulatory controls
	Other Electrical		4	
Disposal:	Degraded Environmentally		14	25 destroyed
	Incinerated		11	
	Landfills -	Cap. & Trans. Prod. Waste	50	
		Elect. Equip.	36	199 in environment
		Paper, Plastics etc.	45	
	Free in Environment		68	

* EPA 1977

PCBs still in the environment amount to some 68 000 tonnes. Of this amount slightly less than half is found in the atmosphere. This suggests a fairly rapid exchange between atmosphere and land and water reservoirs. Atmospheric inputs to lakes and remote areas are therefore thought to be significant.

In the future the disposal/destruction of PCBs will concentrate largely upon the 345 000 tonnes of PCB contained inside of various electrical equipment. Some PCB from the worst of the old chemical landfill sites across North America will be also destructed but this will not probably be a significant amount. A number of technologically sophisticated chemical landfills exist in the United States. They are approved to accept solid and liquid PCB waste (so called Annex II landfills).

As of December 1981 the list of approved landfills is as follows:

- Cecos
  Niagara Falls, NY

- SCA Chemical Services
  Model City, NY
- Waste Management of Alabama *
  Livingston, AL
- Cecos *
  Williamsburg, OH
- Casmalia Disposal
  Santa Barbara County, CA
- US Ecology
  Hye County, NE
- Chemical Nuclear Systems *
  Arlington, OR
- Wescon *
  Grand View, ID
- Chemical Waste Company
  Calaman Hills, CA

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* Landfill approved to accept liquid contaminated with 50-500 ppm PCBs. All others can accept only solids, such as drained transformers, and capacitors, soils, rags, etc., contaminated with low levels of PCBs.

3.3 Size of Current Canadian PCB Problem

The PCBs originally used in Canada i.e. prior to controls implementation amounted to approximate 35 000 tonnes. The inventory of PCBs currently in use or in storage in Canada was collected from the Regions of the Environmental Protection Service of Environment Canada. The totals by province are listed in Table 2 and are summarized below according to use:

	PCBs (tonnes)
Transformers	12 586
Capacitors	2 191
Other Electrical Equipment	15
Nonelectrical Equipment	31
	14 823

TABLE 2 QUANTITY OF PCBs IN USE IN TRANSFORMERS AND CAPACITORS

Province	Type of Unit	No. of Units	Quantity of PCBs (kg)
British Columbia (including the Yukon)	- transformers	762	1 350 000
	- capacitors	7 705	656 000
	- nonelectrical	193	30 800
Alberta	- transformers	828	324 000
	- capacitors	6 361	46 000
	- electromagnets	2	1 100
Saskatchewan	- transformers	199	204 000
	- capacitors	1 988	14 500
Manitoba	- transformers	407	94 900
	- capacitors	2 709	12 600
	- electromagnets	4	1 800
Ontario	- transformers*	5 187	6 980 000
	- capacitors	19 642	473 400
Quebec	- transformers	1 793	2 980 000
	- capacitors	62 937	875 000
	- electromagnets	11	12 400
New Brunswick	- transformers	-	339 000
	- capacitors	-	52 500
Nova Scotia	- transformers	-	294 000
	- capacitors	-	60 000
Prince Edward Island	- transformers	-	11 500
	- capacitors	-	150
Newfoundland	- no PCB inventory has been conducted in the Province of Newfoundland.		
Northwest Territories	- transformers	21	8 900
	- capacitors	152	800
Total			14 800 000 kg (rounded)

* includes electromagnets

PCBs presently in storage for use of awaiting disposal are listed in Table 3. These are quantities which are not prohibited by government regulations. In addition there is a quantity in private storage by two companies in the PCB waste management

business, see Table 4. There is considerable uncertainity in the precise amount of PCB stored by these two companies as the wastes have been placed in storage tanks with other waste materials. The PCB content is estimated to be between 50% and 70% PCB. Finally the distribution of PCBs by industry group is provided in Table 5.

The rate of disposal of PCBs in Canada will depend on the attrition of transformers. This can be expected to take in the order of at least 45 years.

TABLE 3 QUANTITY OF PCBs IN STORAGE IN CANADA

Province	Material in Storage for Use		Material in Storage for Disposal	
	No. of Units	Quantity of PCB (kg)	No. of Units	Quantity of PCB (kg)
British Columbia	-	-	-	21 800
Alberta	7	440	23	3 800
Saskatchewan	-	590	-	2 400
Manitoba	-	1 600	-	-
Ontario				
Quebec	-	10 500	-	156 000
New Brunswick		4 500		9 000
Nova Scotia		19 500		24 000
Prince Edward Island		-		1 350
Newfoundland	- inventory not done			
Northwest Territories	2	90	9	2 100
Yukon	- included in British Columbia inventory			
Total		37 220 kg		220 450 kg
Grand Total				257 670 kg

TABLE 4 QUANTITY OF PCB-CONTAMINATED LIQUIDS IN PRIVATE STORAGE FACILITIES

Name and Location of Facility	Bulk Quantity of PCBs in Storage (kg)
D & D Group, Smithville, Ontario	476 000
Kinetic Environmental Transport Systems, Sherwood Park, Alberta	341 000
Other Storage Facilities	476 000
Total	1 293 000*

* Actual PCB content in the liquids would be no higher than 70% and more likely 50% a meaning of 650 000 to 900 000 kg in storage. (Evans, G., pers. comm., 1981).

TABLE 5 PCB INVENTORY IN CANADA BY INDUSTRY

Industry Sector	Quantity in Use tonnes	% of Total
Utility	3 703	25.1
Pulp and Paper	2 670	18.1
Mining and Smelting	2 071	14.0
Refining (Metal)	105	0.7
Iron and Steel	1 705	11.5
Cement	227	1.4
Chemical Manufacture	101	0.7
Service Industries	2 601	17.7
Petroleum	128	0.9
Other	1 469	9.9
Total	14 780	100.0

(EPS, 1980-81)

4 DESTRUCTION PROCESSES

4.1 General

The destruction processes that are reviewed in this section have been categorized as follows:

- conventional incineration;
- novel incineration;
- chemical processes; and
- physical/chemical processes.

Among the first three categories the division is somewhat artificial although on review there is advantage in making the division. Within each category a number of processes are described.

4.2 Conventional Incineration

Conventional incineration involves the high temperature oxidation of wastes to innocuous oxides (CO_2, H_2O) and inorganic residues that can be discarded without adverse environmental impact. The process ensures that wastes are exposed to high temperature oxidative atmospheres so the prime design feature is efficient fuel consumption. In the conventional sense, air and hydrocarbon fuels are used although the fuel value of the waste may be used provided it does not degrade the high temperature oxidative condition.

Conventional incineration of PCBs produces hydrogen chloride in addition to various oxides. This gaseous acidic compound must be removed from the effluent gases before discharge to the atmosphere. Solids handled by conventional incineration are completely oxidized usually leaving an inorganic ash.

Incineration is an established technology that is used in a variety of waste management applications. As such, it was the technology of choice when regulators set guidelines for the destruction of PCBs. The suggested minimum operating conditions for the destruction of PCBs are:

- 2 second dwell time at 1200°C and 3% excess oxygen; or
- 1.5 second dwell time at 1600°C and 2% excess oxygen.

These conditions apply to the central combustion chamber. There are a number of ancillary components to any incineration system that surrounds the central combustion chamber:

- feed preparation and handling;
- feed charging;
- residue removal;
- gas scrubbing; and
- effluent discharge.

This section on conventional incineration will deal with:

- waste incinerators,
- co-treatment processes, and
- shipboard incineration.

In incinerators specially designed to treat waste all the components are readily identifiable. In co-treatment processes, advantage is taken of an existing industrial process when appropriate time-temperature-oxygen conditions prevail PCBs are fed concurrently with the nominal process feed (e.g. cement kilns). In these situations it is difficult to determine which components are part of the industrial process and which are specifically used for PCB destruction.

Shipboard incineration is a special case which merits its own classification.

4.2.1 Waste Incinerators

4.2.1.1 Rollins Environmental Services, Inc.

Head Office: One Rollins Plaza
Wilmington, Delaware 19899

Site: Deer Park, Texas
Bridgeport, New Jersey
Baton Rouge, Louisiana

Contact: Richard S. Sernyak
(302) 429-2768

The three Rollins incinerators are of a similar design although they are at various stages of approval. The incinerator configuration is given in Figure 1. Solid wastes in fibre drums or 0.2 m^3 metal drums are conveyed into a rotary kiln. Liquid wastes can be fed to the burner compartment. The combuster is a Loddby furnace 1.6 m

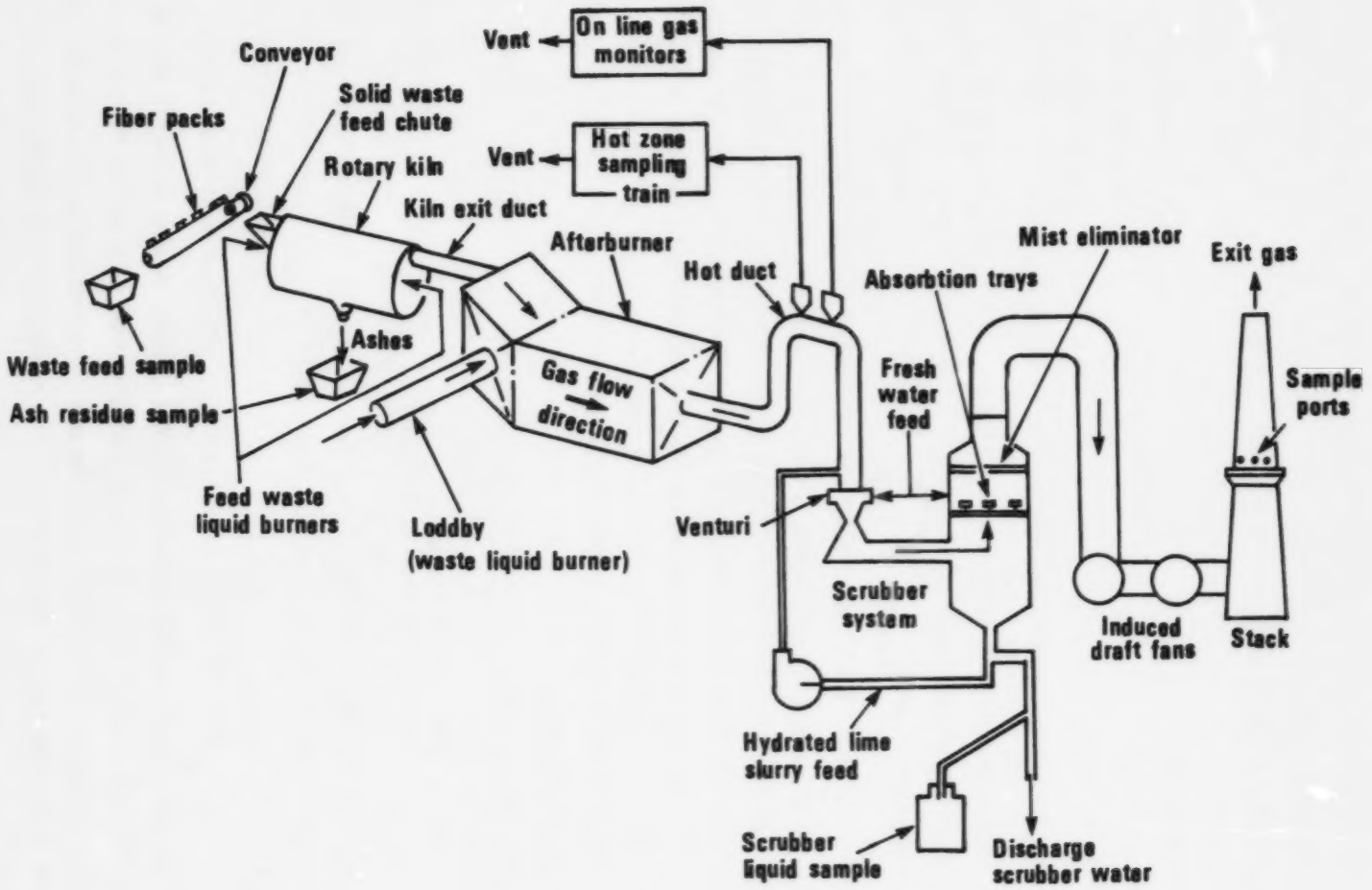

FIGURE 1 SCHEMATIC OF ROLLINS ENVIRONMENTAL SERVICES' INCINERATOR (EPRI, 1979)

in diameter by 4.9 m long. Natural gas and/or No. 2 fuel oil are used for ignition, preheating and flame stability. Compressed air is used to atomize liquids and for the provision of combustion air in a manner that produces a rotary action in the combustion zone. Temperatures in the combustion zone reach 1500°C. An after-burning zone is provided, 4 x 4.3 x 10.6 m, where typical temperatures are 1300°C. The dwell time is 2 to 3 seconds exclusive of the kiln.

The combustion gases are passed through a venturi scrubber/absorption tower combination in which particulates and acid gases are removed from the gas stream. Scrubbing water dosed with lime is added upstream of the venturi throat; this water is recycled (2/3) with make-up water from wells. Induced draft fans are used to drive the gas stream to atmosphere.

The Rollins systems are designed to handle solid and liquid wastes in a variety of forms. Lightly contaminated solids or sludges are fed in fibre drums; heavily impregnated solids (capacitors) are preshredded. Feed rates of up to 2300 kg/h PCB liquid and six 0.2 m^3 drums/h have been projected. The destruction efficiency has been variously reported but efficiencies in excess of 99.9999% have been demonstrated on liquid PCBs. PCBs in shredded capacitors were destroyed at a rate in excess of 99.999%. These systems are large-scale incinerators and are not considered to be mobile.

Rollins incineration experience amounts to 32 years with at least the last six years spent gaining PCB incineration experience. Their Deer Park incinerator has been evaluated to the satisfaction of the US EPA and they are now licenced to burn liquid PCBs.

The Rollins incinerator is technically sound, incorporating stack gas monitoring instrumentation and interlocks which shut-off PCB feed, when required, in accordance with PCB regulations.

Replacement capital investment required, excluding land purchase of approximately 30 hectares (75 acres), would be $25 000 000 as of January, 1982. The rotary kiln, scrubbing system and effluent water treatment system comprise the major portion of this expenditure. The cost figure also includes a shredding and feed system for PCB-contaminated capacitors, PCB liquid storage and feed pumps, an afterburner downstream of the rotary kiln, and lime storage and slaking facilities.

> "To operate such a plant, the annual cost would be $8 700 000. This amount would be increased to $14 075 000 when considering the cost of capital, plant depreciation, taxes and insurance. A breakdown of the figure $14 075 00 is as follows:

Operating and Administrative Expense	$ 8 700 000
Depreciation (20 yrs, straight line)	1 250 000
Interest charge at 16.5%	4 125 000
	$14 075 000

Based on a feed rate of 4 260 kg/h, 1 kg would cost $0.44 to destroy."

Assumptions made during the calculation of these costs included a plant utilization of 310 days on a four shift, seven-day week with a standard 40 hour week for receiving and storage.

The components of the Rollins package are available, some more readily than others. Certain items such as the kiln, after-burner and parts of the scrubbing system would have to be fabricated (in accordance with Rollins design) and are not necessarily off-the-shelf units.

The impact of this technology has been summarized by the US EPA based on the observation of small amounts of dioxins and dibenzofurans in incineration products. An upper limit risk estimate was produced on the basis of series worst case assumptions. Approximately 10 improbable assumptions went into the estimate that produced a result of less than one additional cancer per 50 000 people exposed. This represents a public impact and is rated extremely low.

The presence of PCBs in these incinerators does not pose any additional worker impact provided the usual precautions for handling hazardous materials are observed. The Rollins incineration system has received intense scrutiny from regulators in the US and has met and exceeded all their requirements.

References: (Ackerman et al., 1981; Gregory, 1981; Rollins Environmental Services, 1981; EPRI, 1979)

4.2.1.2 ENSCO Incorporated

Head Office: 1015 Louisiana St.
Little Rock, Arkansas, 72202

Plant Location: Eldorado, Arkansas

Contact: Charles Robertson
(501) 375-8444

The ENSCO incinerator is built at the site of an abandoned oil refinery and

makes use of the steam plant boilers as its combustion and after-burning chambers. The incinerator configuration is shown in Figure 2. Drummed wastes (capacitors) are fed to a totally enclosed shredder. Shredded solids drop into a hopper that feeds an auger that conveys solids into a rotary kiln. PCB liquid wastes are mixed in with the shredded solids or injected directly into the kiln or combustion chamber. The air in the shredder enclosure is drawn through a fan into the rotary kiln.

The rotary kiln is 2.1 m in diameter by 10.4 m long and is slightly inclined down to an ash drop where most of the solid residue drops out. The kiln is double walled with air being drawn through the outer annular space and the canopy covering the interface between the rotating kiln and the feed system. Flue gases from the kiln are ducted to a combustion chamber (85 m^3) where fuel (usually an organic waste) is burnt with air to create the higher temperature zone (outlet temperature 1250°C). A second combustion chamber of similar size acts as an after-burner (outlet temperature 1040°C). The combustion products are scrubbed in a spray tower (combined caustic and lime slurry) prior to demisting and discharge to the atmosphere.

The ENSCO system is designed to operate on solid and liquid wastes; the kiln section can be by-passed for liquid waste applications. PCB feed rates typically are 180 kg/h for liquid PCB (as 81% PCB in oil) and 110 kg/h for solid PCB (as 25% PCB in capacitors). Supplementary fuel amounted to 3000 kg/h averaging 16 400 kW heat input. The PCB destruction efficiency observed was 99.99998%. Based on additional testing done in December 1981, the ENSCO incinerator PCB feed rate will be increased to 8 140 kg/h in mid 1982.

The ENSCO experience (while less extensive than Rollins overall) parallels that of Rollins in PCB incineration. Their interest in PCB destruction has spanned at least six years and they are now licenced to incinerate PCBs.

Similar to the Rollins system, the technology involved is a straight/forward application for a rotary kiln with an after-burner. Process instrumentation provides interlocks to shut down the PCB rate for non-compliance with PCB regulations specifically for kiln temperature, after-burner temperature, kiln and after-burner drafts, CO and CO_2 concentration.

Capital costs would be $5 340 000 as of January 1982, the main components being the capacitor hammermills and feed system, rotary kiln, after-burner, scrubbing system and effluent water treatment facilities. Approximately 30 hectares of land would have to be purchased as an additional expenditure. This cost figure, in addition to these

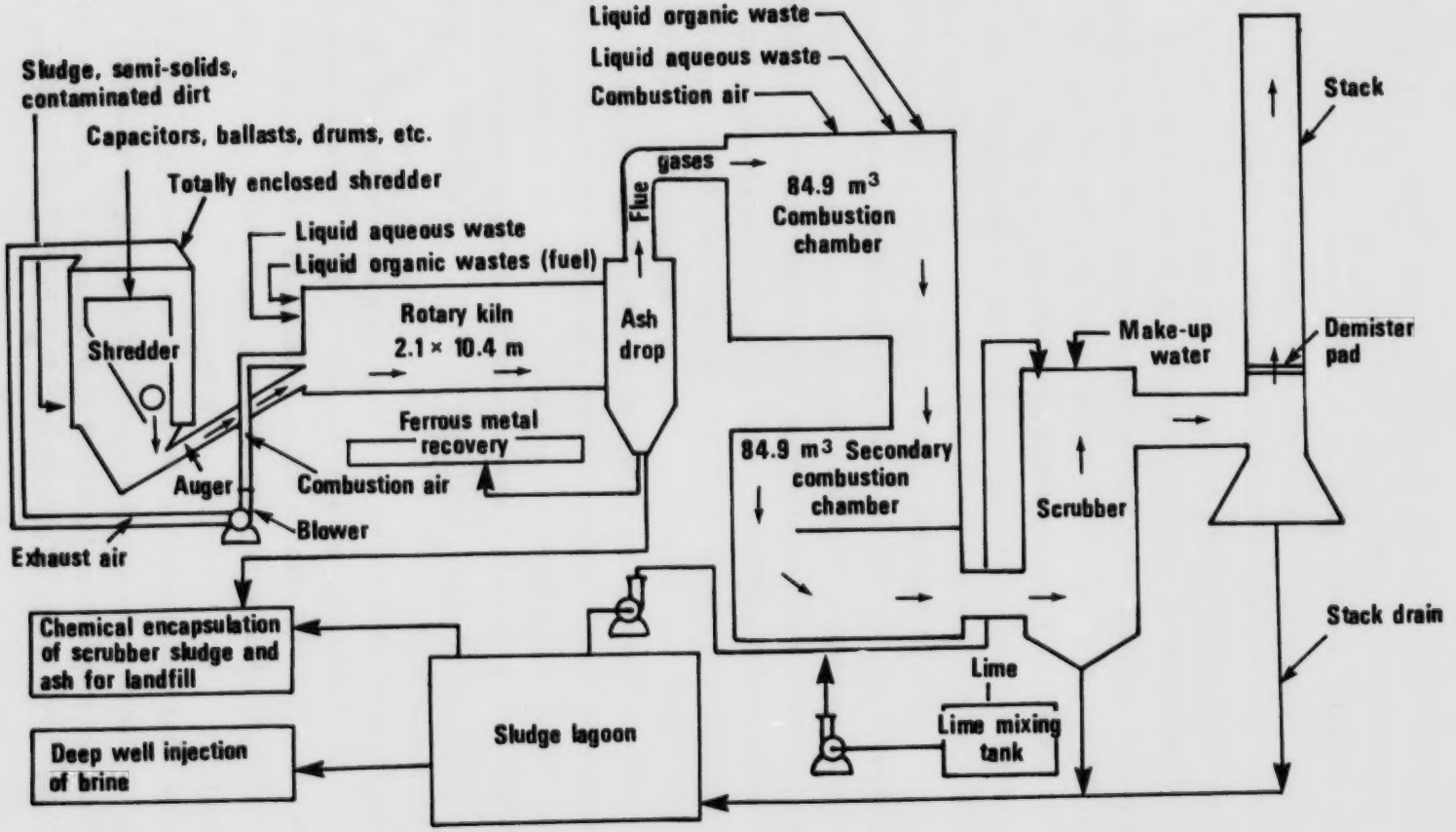

FIGURE 2 SCHEMATIC OF ENSCO INCINERATION SYSTEM (ENSCO, 1981)

modules, also includes costs for receiving and storage, lime storage and slaking, test burn and funding during construction.

The annual operating cost would be $3 920 000 with labour, utility and maintenance allowances composing the major portion. Allowances for insurance, taxes, capital cost and plant depreciation would require a further $1 560 000. The cost to destroy 1 kg of capacitor or liquid is about $0.07. Basic assumptions made for this estimate are:

- a four shift, seven-day week;
- standard 40 hour week for receiving and storage; and
- 85% plant utilization.

As in the Rollins unit, the ENSCO system design is readily available but time would be required for fabrication of the kiln, after-burner and other components in accordance with ENSCO specifications.

The impact of this technology was summarized by the US EPA. For ENSCO, based on observed dioxin and dibenzofuran emission, the additional cancer risk to the public was one cancer for every 2 500 000 people exposed in the worst case fashion. This risk is very low; worker impact is unaffected by the technology over and above that associated with the correct handling of hazardous materials.

The ENSCO system has been approved by the US EPA after scrutiny similar and parallel to the Rollins system.

References: (Ackerman et al., 1981; ENSCO, 1981; EPRI, 1979)

4.2.1.3 Chemical Waste Incinerators

Dow Chemical Company
Midland, Michigan 48640

During the production of a variety of bulk organic chemicals, liquid wastes are produced and are incinerated by chemical manufacturers on their own sites. Many of these manufacturers produce chlorinated hydrocarbon products that require the same downstream technology for combustion products handling as is required for incinerating PCBs.

A Dow Chemical system was chosen as typical of these liquid waste incinerators since:

- Dow is seeking approval to burn contaminated wastes in the US;

- Dow practices liquid waste incineration in Canada; and
- data on the Dow incinerator at Midland, Michigan were readily available.

Collected liquid wastes are mixed, to balance heat content and viscosity prior to firing horizontally into a combustion chamber using air atomization (see Figure 3). Combustion air and secondary air are provided by a blower. The chamber is typically ~100 m^3 in volume. Typical temperatures are in the 1100 to 1200 °C range with dwell times of the order of 2 seconds.

Freshwater is used initially to quench flue gases before they flow to a venturi scrubber and packed bed absorption system. In this section recirculating wastewater is used to scrub the effluent. Finally the effluent is sent to atmosphere through induced draft fans and a stack.

The Dow incinerator is designed to operate on liquids fed typically at ~32 kg/min PCB wastes that have been tested in these units are generally contaminated oils or contaminated waste streams. A support fuel, in this case natural gas, is used to preheat the unit and provide extra heat input as required. Products of the process are CO_2 and H_2O in the stack effluent and hydrochloric acid in the scrubbing wastewater. Scrubbing water would be treated centrally at most chemical sites prior to discharge.

Dow has been burning chemical wastes by this method of incineration for some time. There is no doubt that PCBs can be burned in this manner provided that the thorough mixing of the PCB liquid with a fuel takes place and modifications to existing scrubber and effluent water systems are properly carried out.

This system is only designed for liquid incineration but the possibility of introducing hammermilled capacitors as fluff could be viable.

In order to exemplify destruction efficiency reference is made to a similar incinerator owned by General Electric in Pittsfield, Massachusetts. In a pair of tests, waste oil containing 1.7% PCB was fed at 2-3 kg/min into their incinerator operating at 871°C and then 982°C. The PCB destruction efficiency was in the range 99.99 to 99.999%.

Waste incineration is a well developed technology. In the United States, there are over 200 liquid-injection incinerators in hazardous waste service similar to the one described above, most operating in conjunction with a commercial chemical production facility. (Some commercial waste destruction facilities do exist - roughly a dozen.) Companies marketing waste incinerators are said to number between 50 and 60 in the US although fewer than 30 have sold units.

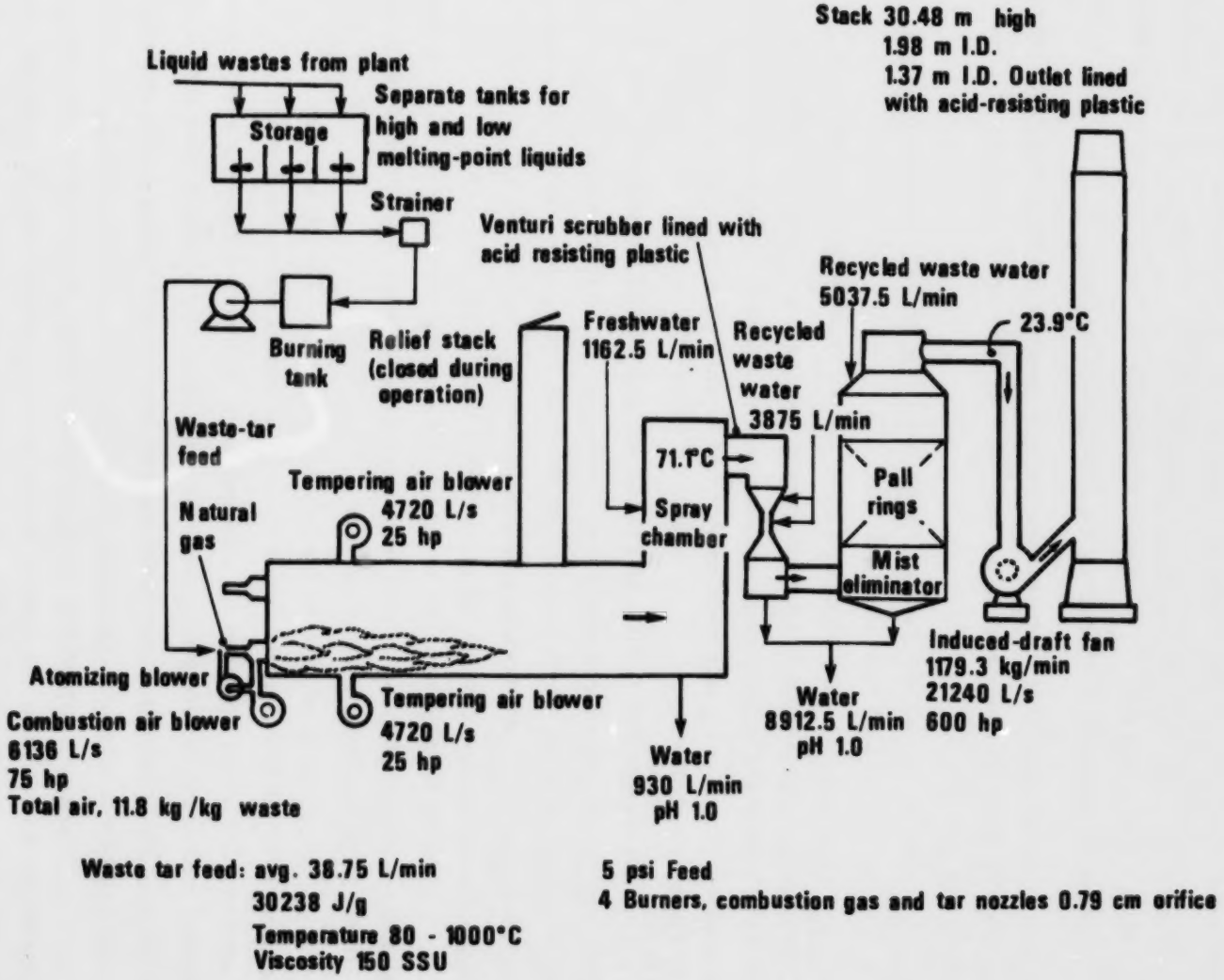

FIGURE 3 HORIZONTALLY FIRED LIQUID WASTE INCINERATION SYSTEM (EPRI, 1979)

The variations tend to centre around the technology of firing wastes into the combustion zone; subsequent scrubbing technology seems to be standard. Three such systems that are often referred to are:

- Prenco vertically fired liquid-injection incinerator;
- Vortex burner; and the
- Sudden Expansion (SUE®) burner by the Marquardt Company.

Prenco is typical of companies such as these; while they report 30 years of experience in the waste incineration business none of their units have been sold for PCB service.

The Vortex burner features tangential firing of fuel/wastes creating a more rapid heat release 1111 kW than other systems.

Capital costs were estimated based on the Dow design and feed rates. They are comprised of those costs involved in storing and feeding PCB liquids to the unit and treating off-gases and scrubber water. Costs for the incinerator, land and laboratory are not included. The existing unit could be modified to suit PCB destruction at a capital cost of $1 630 000.

To operate this facility $2 930 000 per year, would be required. This includes cost on capital, maintenance, and utilities. The biggest expenditure would be for a mixing fluid, such as kerosene, which is added to the PCB liquid. No labour costs have been included as operators are presently available running the incinerator on other liquid wastes. The destruction cost per kilogram of PCB liquid would be $0.22.

The equipment required to modify an existing unit to burn PCBs is readily available. Land considerations could be a serious factor since a lagoon and other water treatment facilities would be required.

The impacts of this technology are minimal. The on-site nature of most operations is advantageous as the risk of moving the wastes elsewhere is minimized. Also, incinerators are often operated by knowledgeable technicians connected with a large chemical production facility giving them the experience and technical backup to operate efficiently. Public impact is minimized by their location and worker health and safety is usually well controlled at such facilities.

On-site or commercial scale chemical waste incinerators have been well accepted by regulators in the United States for PCB destruction. A summary of the approval of sites for PCB destruction in the US is given in Table 6. While most are

TABLE 6 STATUS OF CHEMICAL WASTE INCINERATORS REGARDING PCB DESTRUCTION

Company	Location	Waste/Status
General Electric	Waterford, New York	- approved for destruction of their own PCB-contaminated waste oil
General Electric	Pittsfield, Massachusetts	- approved up to 500 ppm PCBs in fluids; reviewing test for oil containing 20% PCB
Dow Chemical	Freeport, Texas	- approved, contaminated process waste
Dow Chemical	Plaquemine, Louisiana	- public hearing (final stage of approval) contaminated process waste
Dow Chemical	Oyster Creek, Texas	- tested, under review, contaminated process waste
Volcan Material Company	Geismar, Louisiana	- testing contaminated process waste
Diamond Shamrock	Pasadena, Texas	- tested, under review, contaminated process waste
Merlin Associates/ Envirocycle (Genstar)	Chicago Heights, Illinois	- liquid waste incinerator being constructed for PCB-contaminated oil; testing to follow construction

* current in December 1981

dealing with contaminated oils the General Electric facility in Pittsfield, Massachusetts is evaluating concentrated feeds. With final rules now in place in the US it is apparent by the approved activity that facilities for incineration of PCB-contaminated fluids will be increasing substantially.

References: (Oppelt, 1981; MM. Dillon, Ltd., 1981; EPRI, 1979; Gregory, 1981; EPA, 1981).

4.2.2 Co-Treatment Processes. The second major category of conventional incineration is incineration using a combustion process designed for some purpose other than incineration. In these processes combustion conditions are appropriate for PCB destruction during the routine operation of the process for its design purpose. These combustion processes have been labelled co-treatment processes, and are processes based on conventional combustion such as:

- high efficiency boilers fired with coal, oil or natural gas;
- kilns for the production of cement or lime; and
- aluminum melting furnaces.

The PCB waste is generally liquid waste that is fed only at a small fraction of the fuel feeding rate such that the PCB content of the fuel is very low. Within the US regulations there is a special, less restrictive, status for contaminated oil containing less than 500 ppm of PCB. This has led to considerable approval action for burning such low level contaminated material.

4.2.2.1 High Efficiency Boilers. High efficiency boilers burning coal, oil or natural gas are designed to make maximum use of fuel. These units are designed to produce steam for steam-generated electricity or process heating. Many applications have been made for approval in the US particularly for lightly contaminated PCB oils. In the US, regulations governing burning of oils up to 500 ppm PCB are subject to much less stringent rules. To gain approval an applicant need only demonstrate:

- boiler heat release in excess of 15 119 kW;
- stack CO < 50 ppm for oil or gas and CO < 100 ppm for coal;
- 3% excess oxygen; and
- routine stack gas, feed rate and performance monitoring.

These limitations should not limit the applicability of this process to burning only PCB-contaminated oil. Studies by Ontario Hydro and EPRI, suggest that PCBs can be burned at high concentration provided certain feed rate limitations are observed.

The concept of the incineration process is simple. PCB liquids as contaminated oils, pure PCB liquids, or PCB liquids diluted with a fuel oil are fed directly into the

active combustion zone of the boiler. Suitable interlock systems connected with the boiler operation control the PCB feed. Generally, due to corrosion considerations inside the boiler, the chlorine content of the PCB is the controlling factor with respect to the feed rate. As a result, scrubbing of product HCl gas is not practiced. HCl emissions are usually within the local emission regulations by virtue of dilution. The type of boiler selected for PCB incineration depends on the following general factors:

- boiler firing configuration;
- types of fuel; and
- residence time.

Boilers, with horizontally opposed fuel guns, generally give a more thoroughly mixed turbulent flame than do tangentially fired bolers. Coal fired boilers are more likely to be constructed of HCl resistant materials because coal contains small amounts of chlorine (as chloride) not found in oil or natural gas. Residence times in high efficiency boilers are in the range of 1.0 to 3.7 seconds with combustion zone temperatures of 1430 to 1675°C. While these conditions closely match the recommended combustion conditions care must be exercised that "channelling" or "by-passing" does not take place.

Waste firing in surveyed applications extends only to liquid PCBs although the EPRI study discussed firing shredded solid material. Feed rates suggested are the range 150 kg/h (Ontario Hydro) to 300 kg/h (EPRI Study). The solids used in the EPRI system were fed through a rotary kiln with the off gases ducted into the boiler combustion zone. However, it seems unlikely that a high efficiency boiler operator would opt for burning shredded solids.

Destruction efficiencies are usually difficult to define because:

- most tests to date are on lightly contaminated oils with small amounts of PCB fed to the process initially so that it is difficult to determine the actual amount of PCB entering the system.
- sampling of hot, dust laden gas containing large quantities of gaseous diluent makes the detection of even smaller amounts of PCB difficult.

Despite the above restrictions, destruction efficiencies claimed are in the range of 99 to 99.99%.

The operation of high efficiency boilers is a highly developed technology. The introduction of PCB liquid wastes is a relatively simple operation. The monitoring of boiler operation and interface with the PCB feed systems for automatic feed shutdown is a straightforward step.

Compared to the operation of the high efficiency boiler, the operation of the PCB feed systems are not complex and are well within the skills found in boiler operators. The automatic feed shutdown system which interlocks with operational parameters is a well developed technology. Such a system shuts down the PCB feed during a process upset, i.e. furnace temperature too low or combustion efficiency too low. Such a system also controls the feed rate to minimize HCl emissions to within regulatory standards.

Capital costs, for a boiler preprocessing system, including construction funds over a one year period but excluding land costs would be $1 140 000. Such a facility would have the capacity for destroying 260 kg/h of liquid PCBs at 50% concentration in addition to 130 kg/h of shredded capacitors. Total heat release rate would be 2.4×10^5 kcal/h for the preprocessing system. A rotary kiln would be used as the primary combustion chamber to separate PCBs from the shredded solids and to volatilize the liquid PCBs prior to introduction into the boiler which would act as an after-burner.

Operation of this facility would cost $775 000 annually, based on an 85% utilization rate and including cost of capital, labour and maintenance. Unit cost would be $0.26 per kg of PCB destroyed.

Once an existing high efficiency boiler capable of PCB destruction is selected, the front end components for preboiler combustion can be readily purchased.

The environmental impact of boiler incineration should be minimal in a properly operated and safety interlocked system. A particular advantage is that boiler owners/operators in the power generation industry are among the major generators of PCB waste so that action on their part to destroy PCBs in their own boilers is appropriate.

Regulatory agencies have approved a number of high efficiency boilers in the US. A number of other systems are presently undergoing the permitting process. The present status of these applications of high efficiency boiler incineration is summarized in Table 7.

References: (EPRI, 1979; Ackerman et al., 1981; EPA, 1981)

TABLE 7 PCB DESTRUCTION IN HIGH EFFICIENCY BOILERS

Company	Type of PCB Waste Fed	Boiler Fuel	Status
Ontario Hydro	PCB liquids + flushings	Coal	- concept
Florida Light and Power	Askarel (60-100% PCB) at 0.05% of fuel feed rate	Oil	- tested - efficiency > 99.9997%
Continental Can, Hopewell, VA	PCB-contaminated oil	Oil	- tested - operating
General Motors, Bay City, MI	PCB-contaminated liquids	Oil	- tested - operating
Tennessee Eastman	PCB-contaminated liquids	Coal	- tested - operating
North East Utilities, Hartford, CT (Middletown)	PCB-contaminated oil	Oil	- tested
Washington Water and Power Company	PCB-contaminated mineral oils		- test planned December 1981
Union Electric Co.	PCB-contaminated dielectric fluids and solvents		- approved May 1981
Otter Trail Power Company	PCB-contaminated mineral oil		- approved April 1981
Metro Sewers, Cincinnati, OH	Waste oil containing PCB		- test planned
Illinois Power Co.	PCB-contaminated mineral oil		- tested - administration problems
TVA - Widow's Creek	PCB-contaminated oil	Coal	- tested - awaiting results
Duke Power Riverbend Station	PCB-contaminated oil	Coal	- tested - awaiting results
Pennsylvania Power and Light Montour Station	PCB-contaminated transformer oil	Coal	- concept
Baltimore Gas and Electric	PCB-contaminated waste oil		- approved
Potomac Electric and Power	PCB-contaminated waste		- approved
Power Authority of New York	PCB-contaminated mineral oil		- concept
Public Service Co. of New Hampshire	Contaminated mineral oil		- approved March 1980

4.2.2.2 Cement Kilns

St. Lawrence Cement Company,
Lakeshore Road,
Mississauga, Ontario

Contact: L.P. MacDonald
(416) 822-1653

The production of cement involves the calcining of raw materials containing calcium, silicon, aluminum and iron to form the calcium silicates, aluminates and alumino-ferrites that make up cement clinker. The calcining at St. Lawrence Cement takes place in a rotary kiln 3.5 m in diameter by 123 m long (see Figure 4). Slurried raw materials are cocurrently fed with No. 6 fuel oil. Temperatures of 2100°C are reached and residence times of 30 seconds are encountered. Chloride produced combines with alkali metals in the kiln feed volatilizing them as metal chlorides.

"As such the chlorine content of PCB is useful in cement manufacture, in fact chlorine in some form may be required if low alkali cement is produced."

The process parameters at St. Lawrence cement were as follows:

- slurry feed 1400 Mg/day
- clinker produced 900 Mg/day
- No. 6 fuel oil 90 L/min
- chlorinated hydrocarbon 5-10 L/min

The tests carried out used chlorinated hydrocarbon feedstock containing 55% PCB. Destruction efficiencies of at least 99.986% were observed. No PCBs were detected in the gas or solid byproducts but low molecular weight chlorinated hydrocarbons (largely dichloromethane) were detected. PCB destruction efficiences were calculated as if the dichloromethane found was PCB.

A system described by EPRI suggests a rotary kiln preprocessing unit for solid PCB wastes. This system is interfaced with the kiln in the same way the preprocessing system is interfaced with the power boiler.

For a cement kiln preprocessing system with a heat release of 6.5×10^5 kcal/h, capital costs involved would be $1 600 000. This figure includes funds for a one year construction period but no land costs. Capacity of system would be 710 kg/h of liquid PCBs at 50% concentration and 350 kg/h of solid PCBs in the form of shredded

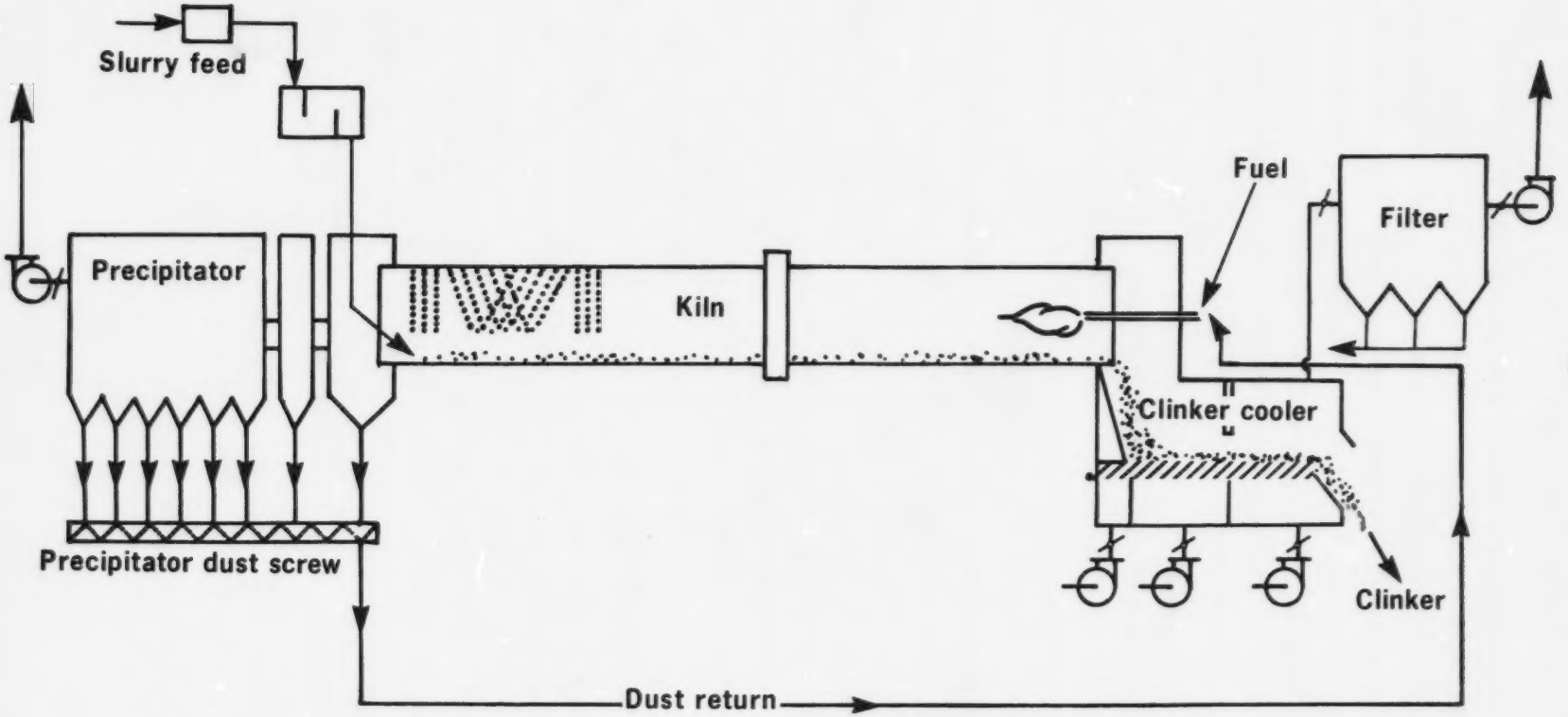

FIGURE 4 WET PROCESS KILN (St. Lawrence Cement Co.)

capacitors. Costing was based on using a rotary kiln as a primary combustion chamber. Both capital and operating cost figures are based on up-dating costs present in the EPRI Guidelines for Disposal by Thermal Technology (1979).

Operating costs of $1 140 000 per year can be expected based on 85 per cent utilization. Destruction of one kg of PCB in this system would cost $0.14.

As in the case of high efficiency boilers, once an existing cement kiln capable of PCB destruction is selected, the kiln precombustion equipment can be readily purchased.

The operation of the cement kiln itself is a fairly well developed technology. The front end equipment comprised of a rotary kiln, enclosed shredders, and pumps are not complex in operation. As with the high efficiency boilers, the automatic feed system which interlocks with operational parameters such as furnace temperature, combustion efficiency and HCl emissions, is technically sound.

PCB destruction in cement kilns has minimal environmental impacts. The tests at St. Lawrence did show an increase in dust emissions which may have been associated with the formation of a ring of agglomerated material in the kiln during chlorinated hydrocarbon incineration. this problem and the local public pressure to improve emission monitoring techniques and emergency interlocks has stopped further testing. Cement kiln incineration as a technology has the support of provincial and federal environmental ministries; it is a recommended method in their guidelines for PCB destruction.

Reference: (MacDonald et al., 1977).

4.2.2.3 Other Kiln Processes. Two other cement kilns and 2 lime kilns have been considered for PCB destruction.

Company	Kiln Type
Peerless Cement, Detroit, Michigan	cement
Energy Optimization, Pittsburg, Pennsylvania	cement and lime
Continental Can, Hopwell, Virginia	lime

The Peerless Cement Company performed PCB test burns in their kiln in Detroit. The kiln had a residence time of 10 seconds at a temperature of 1270 to 1390°C. Destruction efficiencies average in excess of 99.99%. Intense local pressure including adverse reaction from the Canadian side of the border in Windsor Ontario caused the Company to cancel its plans to burn PCBs.

Energy Optimization presently have an application before the US EPA to burn PCB (contaminated oil) in a cement kiln near Pittsburgh, Pennsylvania. This company previously had applied to burn PCBs in a lime kiln in Branchton, Pennsylvania but have cancelled these plans.

A lime kiln in Hopewell, Virginia owned by Continental Can was evaluated for PCB destruction in 1976. The kiln was a 226 Mg/day rotary lime kiln 3.4 m in diameter by 80 m long operating at 1260°C. Their tests suffered several difficulties and PCB destruction has not been reconsidered since 1976. Destruction efficiencies were estimated at approximately 95%.

References: (Ackerman et al., 1981; EPA, 1981)

4.2.2.4 Aluminum Melting Furnace Co-Treatment

Aluminum Company of America (ALCOA)
P.O. Box 3567
Davenport, Iowa 52808

Contact: Marshall Sonksen
(319) 359-2754

ALCOA'S aluminum fabricating plant located near Davenport, Iowa (Riverdale) has a dual fuel (gas/oil) fired aluminum melting furnace that has EPA approval to burn PCB-contaminated waste oils stored at the Davenport facility. A test burn was carried out in July 1981 under the watchful eye of the US Environmental Protection Agency, and approval granted in November 1981. They are required to preheat the furnace to 1150°C prior to introducing the PCB waste oil, maintain excess oxygen at 3%, and maintain the combustion efficiency @ 99.9% as indicated by CO emissions. Their permit is limited to the 6-8 million litres of the 350 mg/kg PCB-contaminated waste oil collected by ALCOA prior to discovering the PCB contamination.

References: (Sonksen, pers. comm. 1982).

4.2.3 Shipboard Incineration

4.2.3.1 MV Vulcanus

Head Office: Chemical Waste Management Inc.
2131 Kingston Court S.E.,
Marietta, Georgia 30067

Contact: Al McCoy, PCB Sales Supervisor
(404) 952-0444

This is basically a traditional incineration method but aboard a ship at sea thus limiting the possible hazardous effects on any population.

The MV Vulcanus is a 100 m long by 14 m wide ship with a maximum draft of 7.4 m. The ship houses two high capacity liquid-injection incinerators which are capable of combusting PCB-contaminated wastes at a rate of 22 Mg/h and a flame temperature of 1500 to 1600°C. The ship has a tank capacity of 3700 tonnes and operates by loading the PCB waste into its 15 tanks on shore. The practice has been to travel to an EPA approved location in the Gulf of Mexico where the wastes are incinerated. An extensive monitoring system ensures that the PCBs are destroyed to 99.995%.

The Vulcanus can only incinerate pumpable liquids that contain solids smaller than 2 mm, although the design concept for costing purposes included a rotary kiln for solids. A chlorine content of 70% on the PCB molecule represents no incineration problem. The PCB waste must not be capable of attacking mild steel.

The Vulcanus has been operating successfully since 1972 in Europe and the USA. In recent EPA tests the Vulcanus incinerated 2 650 000 L of PCB transformer fluid to an efficiency of 99.999% without significant formation of dioxins.

Incineration at sea of chlorinated wastes has been practiced for several years in Europe. Operating experience in the form of routine burning of PCB liquids is nil at the present time. This technology can be considered to be in its middle stages of full testing. Moderate technical skill would be required for facility operation.

The capital investment required for such a facility would be at least $7 000 000 excluding land costs for an on-shore support facility based on the 1981 costing figures provided by E.T. Oppelt.

Operation of an incinerator ship over a one year period would require a minimum of $6 020 000 including cost of capital. Utilities, labour and maintenance would be the major operating cost contributors. This figure is based on the assumption that

design concept is for a rotary kiln incinerator followed by a liquid injection incineration after-burner. Design feed rate is 6000 kg/h liquid PCBs or 3000 kg/h solids, and facility operates 12 hours per day, seven days per week. Operating costs were calculated by comparing costs for a Rollins incinerator to costs for sea disposal in a format similar to operating costs as given in EPRI Guidelines for Disposal by Thermal Destruction.

The cost of destroying one kilogram of PCB liquid would be $0.23 using such an arrangement.

The environmental impacts of the Vulcanus are similar to those of all other incinerators. Hazards are minimal for the worker or public provided adequate care is taken in running the process. The impact of incineration on the environment is lessened by the fact that it occurs at sea well removed from land and population. Repeated EPA testing has shown that shipboard incineration does not affect fish and other sea life.

The EPA has given permission for 2 shipboard incineration runs on the Vulcanus and is continually testing and monitoring the ship's incinerators. The Vulcanus is prepared for the commercial incineration of PCB liquid wastes once their testing program has been completed.

References: (Oppelt, 1981; Jordan, 1982; Chemical Waste Management Inc.).

4.2.3.2 Other Shipboard Incinerators

At-sea Incineration, Inc. (ASI)
534 East Putnam Avenue
Greenwich, Connecticut 06830

Contact: Barry S. Cogan
Tel: (203) 629-3711

At-Sea Incineration, Inc. will operate two incinerator ships, each containing two liquid injection incinerators. The rated throughput of each incinerator is 3.22×10^8 kW. Hazardous wastes will be incinerated at an EPA approved burn site east of Cape Henlopen, Delaware. ASI expects to have the two ships operational by early 1984.

References: (Hazardous Materials Intelligence Report, 1982).

4.3 Novel Incinerators

Novel incineration, a second category of destruction process by incineration, while still deriving its thermal energy from the oxidation of a fuel, has some special features that sets it apart from ordinary incinerators which burn fuel with air in a simple combustion zone. We have identified five types of novel incinerators:

- oxygen incinerators;
- molten salt incinerators;
- fluid bed incinerators; and
- diesel processes.

Oxygen incinerators use pure oxygen or at least enriched air to oxidize the fuel. Higher temperatures are achieved and smaller volumes of products are produced for subsequent scrubbing. Molten beds achieve a similar effect and also provide a higher unit volume concentration of oxygen. Fluid beds make use of fluidized solids in the combustion zone to increase the heat transfer to the waste. Catalysts can also be supported on the fluidized solid. Finally the diesel process involves waste destruction during the combustion of fuel in a diesel engine.

4.3.1 Oxygen Incinerators. Incineration using oxygen instead of air as the fuel oxidizer has the advantages of

- higher temperatures than conventional incinerator; and
- reduced combustion product volume.

Burner design and materials of construction tend to create some problems which are being overcome. Pure oxygen requires special handling and the use of tempering air can lead to additional chemical consumption on scrubbing by virtue of nitrogen oxidation.

4.3.1.1 Pyro-Magnetics Mobile Hazardous Waste Processor (MWP-6000)

Head Office: Pyro-Magnetics Corporation
200 Essex Street
P.O. Box 288
Whitman, Massachusetts, 02382

Contact: D.M. Dyer
(617) 447-0448

The Pyro-Magnetics Mobile Hazardous Waste Process (MWP-6000) is an integrated waste processor which makes use of an oxygen incinerator as its central waste destruction unit. The oxygen incinerator accepts liquid wastes directly or processes off gases from a rotary kiln or a Special Melting Treatment (SMT) Unit. The SMT Unit appears to be technology base for Pyro-Magnetics Corporation and they have used it to advantage in their integrated waste processor.

The MWP-6000 process configuration is shown in Figure 5. Solid wastes, depending on waste make-up are fed either to the rotary kiln unit or to the SMT Unit. Rotary kiln feed can be shredded and screw fed intro the kiln or fed through a sludge injector. The kiln, when operated, burns fuel with air producing an operating temperature of 980°C. The combustion products are ducted to the Secondary/Liquid Combustor (Oxygen Incinerator). Ash is removed through as ash breach.

Solids fed to the SMT Unit are pyrolyzed and melted in an inductively heated molten iron bath operating at 1650°C. Siliceous materials are slagged off. The atmosphere in the SMT Unit is controlled to control the bath composition and the volume of product gases that are ducted to the Secondary/Liquid Combustor.

Liquids are injected directly into the Secondary/Liquid Combustor through two oxygen burners. Additional air is blown in to temper the combustor temperature to about 2200°C. If necessary, liquid wastes like PCBs can be blended with fuel oil to maintain heat content and operating temperature. The combustor is 0.8 m in diameter by 2.4 m long followed by a secondary chamber, 10.7 m, that gives a 2 second dwell time at 1260°C exit temperature.

The product gas scrubber is driven by an induced draft fan that keeps the whole system under a negative pressure. All breaches are interconnected so the processor runs at a negative pressure ensuring that no spurious gases are emitted. A caustic scrubber and quenching system is used to cleanse acids and trace organics from the flue gases.

The unit is designed to handle 2700 kg/h of solid waste. PCB liquids (50% in fuel oil) are designed to be fed up to 0.6 m^3/h. Oxygen consumption of 3 kg/kg of PCB is only slightly in excess of stoichiometric requirements. Power requirements amount to 1000 kW when the SMT is utilized and only 100 kW for the liquid system.

In concept form the MWP 6000 can handle a variety of PCB waste types. The multiple feed systems for solids and liquids should provide enough flexibility to handle most PCB wastes. Destruction efficiencies of 99.999 943 were obtained during the March, 1982 test burn held in Tullahoma, Tenn. for the EPA. All the integrated units are mounted on 2.4 x 14 m mobile truck beds. In addition to the units described, a mobile lab and a chemical service trailer complete the MWP 6000 package.

As suggested above, it is believed Pyro-Magnetics main technological advantage is the SMT Unit and the oxygen incinerator, which are both unique. The wedding of this controlled atmosphere high temperature material processsor with a controlled

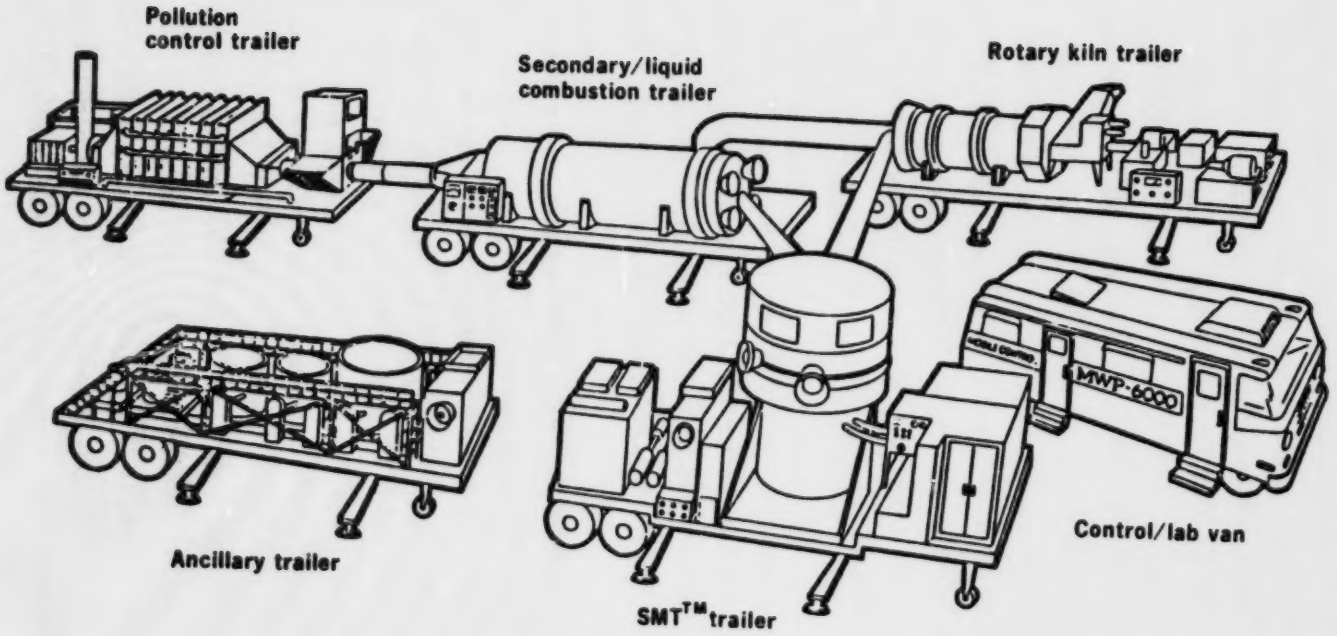

FIGURE 5 MOBILE HAZARDOUS WASTE PROCESSOR (Pyro-Magnetics Corp.)

atmosphere burner is a natural outgrowth. The rotary kiln unit is a useful adjunct to complete the waste handling package. The units are apparently being tested one by one. The Liquid Combustor was the subject of EPA approved tests at Arnolds Labs (University of Tennessee, Tullahoma, Tennessee) in March 1982. Test results were excellent.

The solid technology has not been totally tested on PCB wastes. The ability for such a system to successfully destroy solids in the form of shredded capacitors, etc. should be more closely examined as the original technology described here included a rotary kiln upstream of the SMT equipment whereas a more recent version of the system omits the rotary kiln. The system appears to have the capability of readily destroying liquid PCB wastes.

The cost per unit PCB destruction by this technology is estimated to be $5.00 US dollars per gallon of low grade waste $10.00 US dollars per gallon of medium grade waste and $15.00 US dollars per gallon of high grade waste. This cost includes the rental charged by contractor for equipment in addition to heavy fuel oil and electrical operating costs.

The technology also carries the stipulation that approximately 30 by 30 m of land be made available. Capital allowances were built in to compensate for additional effluent water treatment facilities such as a lagoon.

The equipment is readily available from the contractor on a cost per unit destroyed basis.

Public impacts would be minimal if the company plans are implemented. The MWP 6000 system is fundamentally a non-polluting process; effluents are inert solids and innocuous gases. The mobile aspects could satisfy public demands that wastes be destroyed where they are generated or exist. Worker impacts are those of a hazardous waste handling operation and are usually well controlled.

As indicated above, the MWP 6000 process has undergone testing according to US EPA rules. The procedure appears to be running smoothly, the oxygen combustor was tested in March 1982. High levels of destruction were achieved.

References: (M.M. Dillon Ltd.,1981, 1982, Pyro-Magnetics, 1981).

4.3.1.2 Chemical Plasma Process

SJT Consultants
2697 Steeles Avenue West
Toronto, Ontario

Contact: Dr. Stanley Townsend
(416) 661-2685

This process involves the controlled burning of fuel and liquid waste in pure oxygen in such a manner as to maximize the temperature achieved in the combustion zone. The process has grown out of magneto-hydrodynamic (MHD) process development. In the MHD processes developed by SJT, plasmas were created from the chemical energy available from combustion. Temperatures in excess of 5000°C are achieved. Their MHD reactors have been modified with gas scrubbing equipment. Hydrochloric neutralization is achieved by caustic injection along with the waste feed or in the scrubber.

Limited information is available on this process or on the status of their testing program.

The future development plan for this process is to make the unit mobile.

References: (Townsend, 1982; Johnston, 1982)

4.3.2 Molten Salt Processes. Molten salt processes involve oxidation of waste PCBs with the same chemical result as the foregoing combustion processes. These processes are different because they take place in a condensed phase while still operating at relatively high temperature. The effects are twofold:

- wastes are contacted with a more concentrated oxidant, i.e. oxygen dissolved in the molten phase; and
- wastes are preheated more rapidly up to reaction temperature since the molten medium has greater heat capacity per unit volume.

As a result lower temperatures and shorter residence time accomplish similar destruction efficiencies. Another potential advantage is the ease with which neutralizing chemicals can be used directly in the combustion zone, simplifying the process by avoiding the acid gas scrubbing after the destruction reaction.

4.3.2.1 Rockwell's Molten Salt Destruction Process

Head Office: Rockwell International
Energy Systems Group
8900 DeSoto Avenue
Canoga Park, California 91304

Contact: J.G. Johansen
(213) 700-3508

The Rockwell Molten Salt Destruction Process and technology achieves essentially complete decomposition and destruction of hazardous chemical wastes by exposing these materials to a pool of molten sodium carbonate at temperatures ranging from 840 to 982°C. The process is highly efficient and has been effectively demonstrated in both deficient and excess oxygen modes of operation.

In the process, waste and air are introduced beneath the surface of a pool of molten salt in a vertical, cylindrical, atmospheric pressure vessel. Both solid and liquid wastes can be handled.

If the chemical waste is combustible (minimum of 10 467 J/g), exothermic reaction takes place rapidly, and the waste material breaks down into its constituents which are realeased as gases: carbon dioxide from the carbon element in the waste and steam from the hydrogen component. If sulphur, phosphorus, chlorine, or other halogens are constituents of the waste, they are retained in the melt as the corresponding sodium salt. Uncombustible portions of the wastes are reatined as ash in the melt.

In cases where wastes to be disposed of have a Btu value lower than 10 467 J/g, a combustible material must be coburned with the waste to increase its heating value. This additional material could be another waste or some inexpensive, combustible material such as coke, waste oil, scrap solvent, or coal. This supplemental heat is required only when low-Btu value wastes are destroyed. In some cases, combustion of the waste may be enhanced by way of oxygen-enriched air, in which event no other combustible material may be necessary.

Since the reaction of the waste in the melt is rapid and complete, the effluents require little or no further cleanup and present no undersirable elements to the atmosphere. This environmental acceptability may lend itself to readily approved siting and permitting. MSD plants require minimal size sites, are simple to operate, and are not prone to upset.

The Rockwell molten salt technology also lends itself to recovery of energy or material resources from the waste. The gases are produced at temperatures ranging up to

982°C and can be conducted through waste heat recovery systems to produce steam or power. Valuable metals (silver, vanadium, tin, and chromium) which may occur in some wastes may be recovered as either pure metal or a metallic salt from which the metal may be recovered by standard chemical procedures.

The spent salt is withdrawn and allowed to solidify, following which it can be disposed of as nonhazardous ash.

Rockwell has engineered and designed two basic combustor systems. The Santa Susana Test Facility has a multi-purpose ceramic-lined vessel with appropriate equipment to feed the waste and withdraw the molten salt, either continuously or on a batch basis. Instrumentation continuously monitors stack gases during operation.

The Molten Salt Combustor is an all metal combustor vessel providing for continuous waste feed and a spent melt overflow discharge which takes place as wastes are combusted and ash builds up in the melt (see Figure 6).

A simplified diagram and flow chart of a commercial system using the combustor design of Figure 6 is shown in Figure 7. The system incorporates three all-metal combustor modules with a capacity of up to 1 tonne/h of waste. This equipment will handle liquid or solid wastes such as PCBs with destruction efficiency of 99.9999% or more.

A schematic of a transportable system, available in 1983, using the combustor in Figure 6 which will handle up to 102.1 kg/h of halogenated-type waste, such as liquid PCB, or other combustible chemical wastes is shown in Figure 8. This unit could be installed onsite to handle small quantities of waste as produced. Alternately, it can be moved from place to place for destruction of larger quantities of accumulated waste.

Rockwell has conducted test burns on many typical varieties of hazardous wastes with destruction values of at least 99.9999%. Extremely sensitive gas analytical equipment and sampling devices have been involved in these tests. In all cases, destruction efficiency exceeds minimum EPA requirements and off-gas quality is far below EPA thresholds.

4.3.3 Fluid Bed Processes. Fluid bed processes operate on the same general principle as molten beds except that the bed material is actually a solid. The solid, in a fine granular state is fluidized by blowing a gas through it. The simplest applications use air as the fluidizing gas. The bed is heated by combustion of supplementary fuel and/or waste. The reaction of material fed to the bed is facilitated as before by the heat content of the bed. The reactions will take place in the gaseous phase rather that in the molten phase as before.

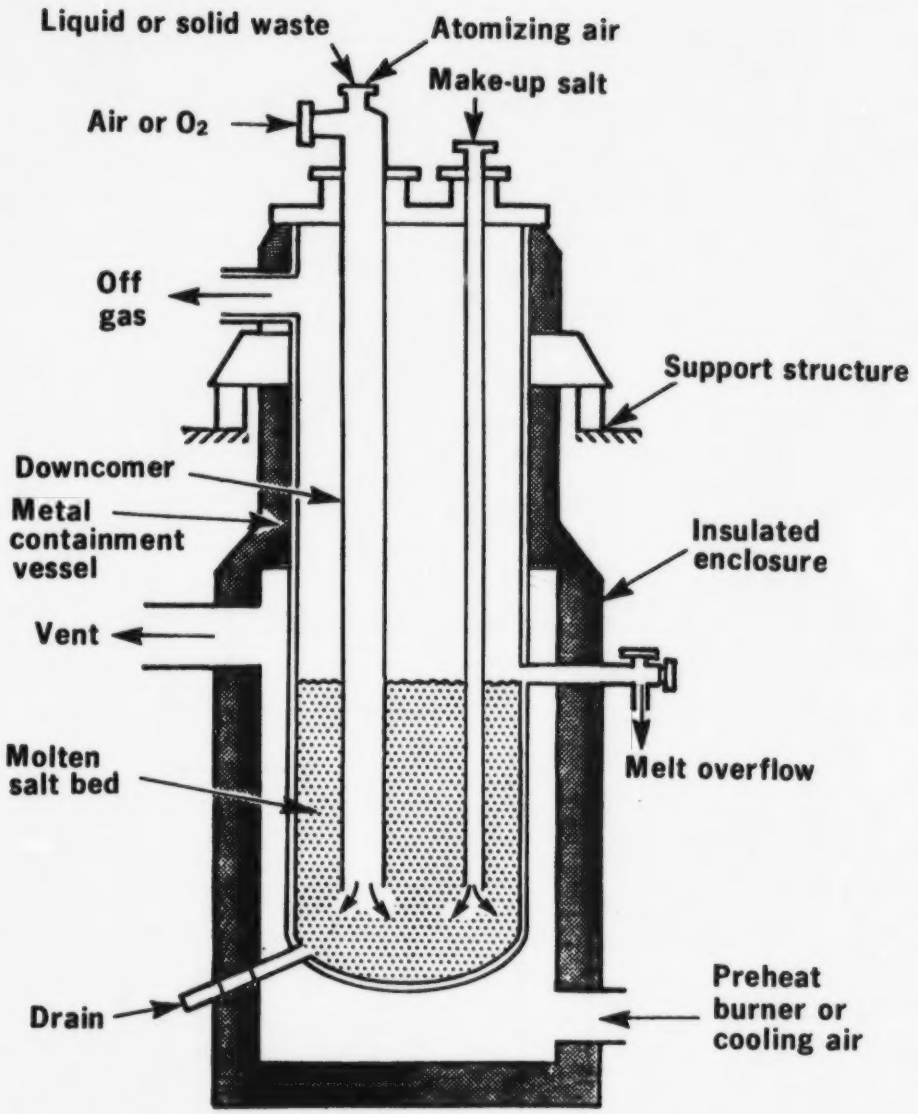

FIGURE 6 SCHEMATIC OF MOLTEN SALT COMBUSTOR - COMMERCIAL
(Rockwell International)

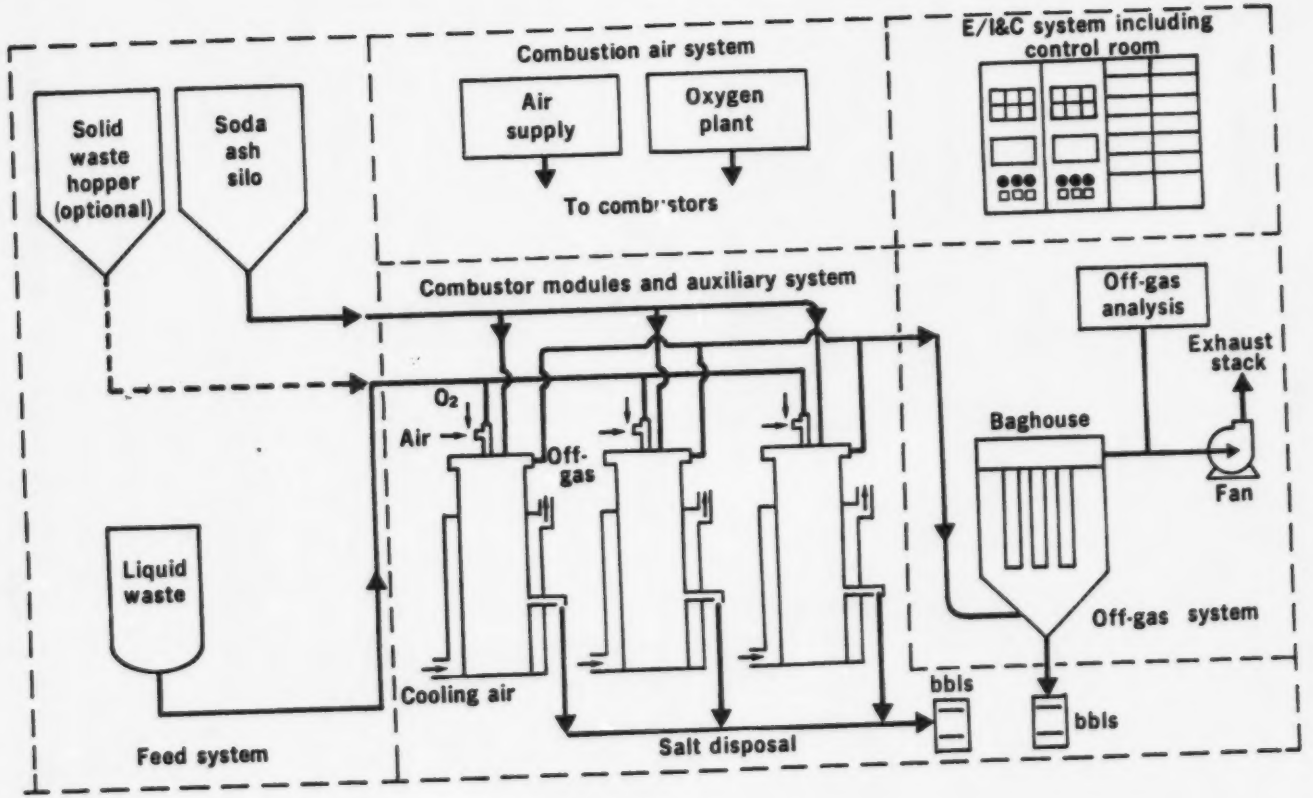

FIGURE 7 MSD - COMMERCIAL STATIONARY UNIT (Rockwell International)

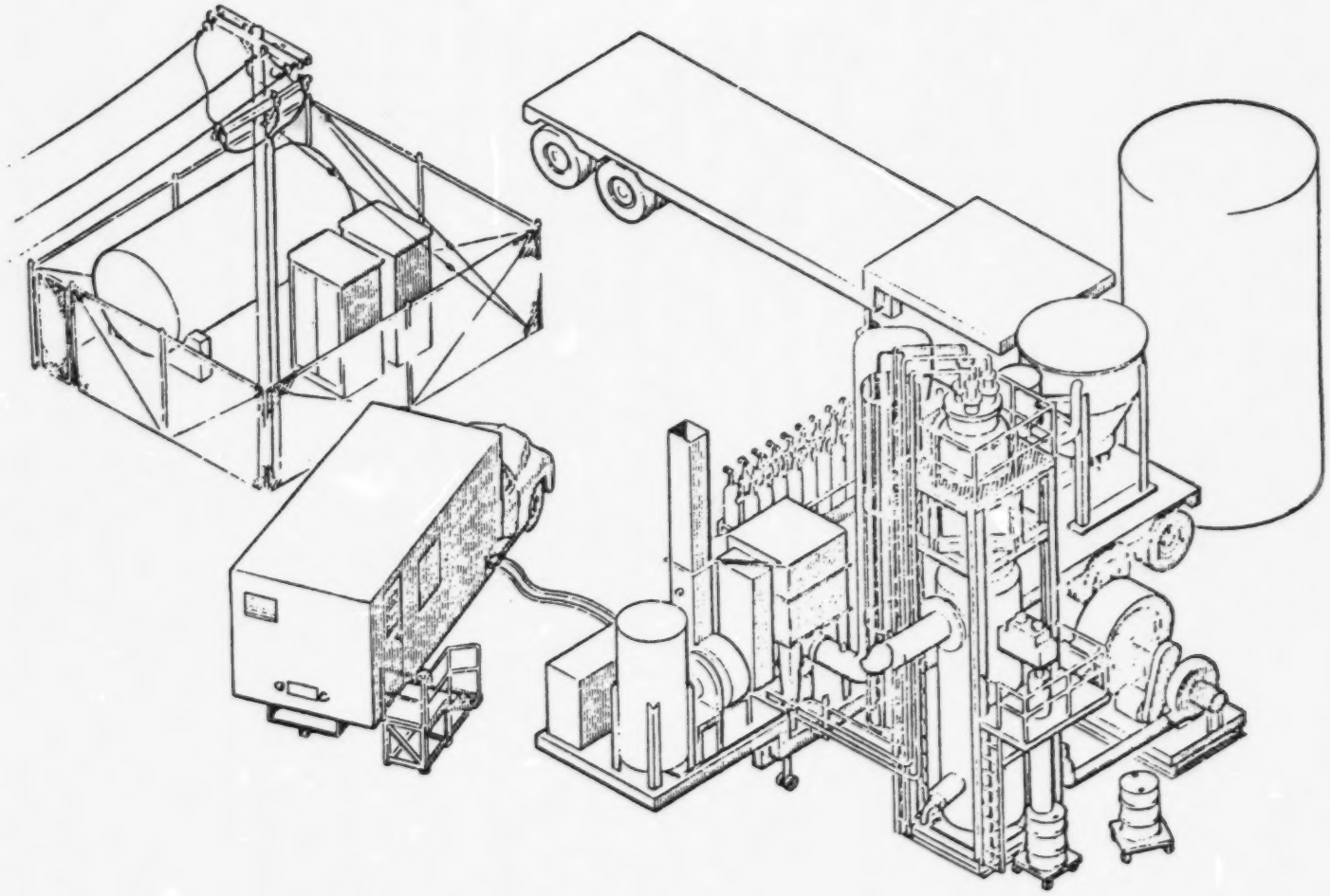

FIGURE 8 PORTABLE MSD UNIT (Rockwell International)

4.3.3.1 Rockwell's Fluidized Bed Incinerator

Head Office: Rockwell International
Rocky Flats Plant, Energy Systems Group
P.O. Box 464
Golden, Colorado 80401

Contact: Jerry Langheim,
Manager, External Communications
(303) 497-4255

The Rockwell fluidized bed incinerator uses two fluidized bed reactors arranged in series to carry out the destruction of PCBs. The pilot testing facility, has been operated for testing of PCB destruction (see Figure 9).

The bed material in the primary reactor was sodium carbonate with a CR_2O_3 catalyst (20% Cr_2O_3 and $A1_2O_3$). Hydrochloric acid produced by combusting PCBs reacts with the sodium carbonate portion of the bed material to form sodium chloride. This is a surface reaction on the sodium carbonate particles. Sodium chloride is removed from the surface of the sodium carbonate particles by attrition caused by the fluidized condition of the bed. The sodium chloride and some sodium carbonate is elutriated from the bed by the fluidizing gas, preventing excessive buildup of sodium chloride in the bed.

The beds are preheated by burning kerosene in air. The primary fluid bed reactor is operated at 590-600°C. When waste or fuel/waste mixtures are being fed the temperature is controlled by diluting combustion air with nitrogen. This pilot unit was tested with 13% PCB in kerosene fed at a rate of 3 kg/h. Off gas from this fluid bed reactor is cycloned to remove sodium chloride and ash, and fed to a second fluid bed reactor loaded with catalyst, operating at approximately 700°C. This second reactor acts as a catalytic after-burner. Gas from the second reactor is cycloned and passed through sintered metal filters prior to sampling. In this test rig an air ejector provides the motive force for the gases and is backed up by high efficiency particulate air filters. The unit was designed originally to burn transuranic waste so a high degree of emission protection was used. For PCB destruction this particular configuration may not be needed.

A significant feature of this process is the all metal construction. Process temperatures are low enough to avoid the use of refractories.

At this point only brief tests on PCBs have been completed so that details of waste types that can be fed and residue removal practices have not been tested. Destruction efficiencies observed in the PCB test burn exceeded 99.9999%. The observed

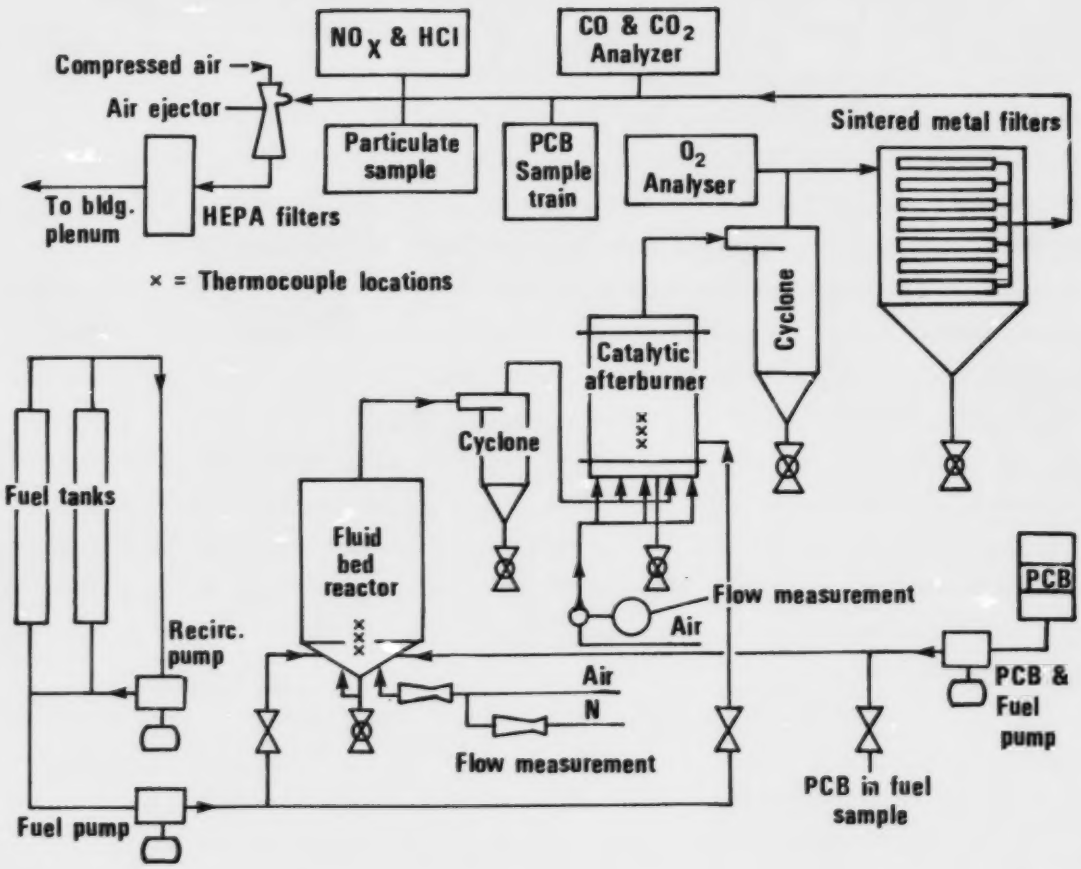

FIGURE 9 PILOT SCALE FLUIDIZED BED UNIT (Rockwell Intrnational)

combustion efficiency was 99.89% (CO_2/CO_2+CO) with 9.3% excess oxygen. NO_x emissions were low and HCl removal efficiency was 98%.

The pilot plant presently has had 5000 h of general operating experience on various wastes including the test with PCBs. A medium level of skill is required by operating personnel. The PCB process is still in the middle stages of development requiring further technical sophistication in regards to continuous replenishment of bed materials for large scale operations.

Capital and operating costs for the pilot facility would be $800 000 and $1 200 000 respectively based on a 45 kg/h through put. Unit cost for PCB destruction would be $2.73/kg. This figure could be reduced significantly for an operating plant scale up to a capacity of 4500 L/day. Anticipated unit costs for this operating plant would be approximately $1.31/kg. Capital costing is exclusive of land costs. Major contributors to operating expenditure would be cost of mixing fuel and bed material. Annual operating costs are based on 85% utilization with a full 4 shift, 7 day per week schedule.

Capital costs were derived by summarizing present costs for the following components of the system: receiving and storage facilities, feed system, barrel pumping and feed pumps, two fluid bed reactors, two cyclones, filters, air ejector, instrumentation and controls, laboratory and office, and funding during construction.

This Rockwell process is not yet available commercially as a PCB destruction system.

The environmental impacts of the process would have to be assessed upon testing of a scaled up version. The destruction efficiency is comparable to that achieved by conventional incineration. The removal of HCl and CO would have to be followed in a full scale test.

Rockwell engineers in a news release put forth the feasibility of mounting the system on rail cars to take the processor to waste sites. Such an arrangement would decrease the adverse local reaction to permanent PCB destruction facilities.

The US EPA has endorsed this process as "a viable alternative for destroying liquids with a high PCB concentration." However, they warn that future exploitation must be carried out with their approval of testing of a more highly developed process. The process exists in the public domain in the US as the work was carried out under Department of Energy contract.

References: (Johnson, 1981; Langheim, 1981; Oppelt, 1981).

4.3.3.2 Other Fluidized Bed Combustors. Other potential fluidized bed units that could be applied to the PCB destruction problem were reviewed briefly by TRW Inc. for the US EPA.

System Technology Corporation (Systech) of Franklin Ohio have tested a fluid bed (7.6 m in diameter, 1.0 to 1.8 m deep) on phenolic wastes. Feed rates in the range of 1 to 10 Mg/h for liquids and up to 135 Mg/h of solid (municipal) wastes have been burned.

Union Oil Company, Union Maine and Hazen Research, Inc. of Golden, Colorado are also considering fluidized beds for in-house destruction (refinery wastes) and as a marketable system.

References: (Ackerman et al., 1981).

4.3.4 Diesel Processes. The use of a diesel engine as a PCB incinerator is similar to the co-treatment processes described previously. The diesel is designed primarily to produce motive power; during this process a moderately high temperature environment is created in which PCBs can be combusted. The diesel engine is fundamentally more suited than the gasoline engine as the low volatility diesel fuel is sprayed into the cylinders. Thus the fuel system need not be modified significantly to burn PCB.

Conventional incineration parameters for temperature and residence time suggest that the diesel engine is too cool and lacks the residence time. Furthermore, the cylinder walls represent enormous thermal sinks that could cause very cool layers where combustion could be even further retarded. Also, concerns for the materials of construction exist in view of the production of hydrogen chloride as a combustion by-product.

4.3.4.1 The D & D Group, Inc.

P.O. Box 372
Smithville, Ontario
L0R 2A0

Contact: T.W. Drew, President
(416) 957-3323

The application of this technology by the D & D Group makes use of a

150 kW six cyclinder in-line Dorman diesel (Dorman Division of GEC (UK)). The diesel drives an electric generator which is under load during operation. The exhaust from the diesel is scrubbed with water that is neutralized with limestone to consume the hydrogen chloride produced. After scrubbing the exhaust is passed through an activated carbon filter and discharged to atmosphere. The fuel mixture consists of diesel fuel and askarel. While still in the development stage the optimum fuel : askarel ratio has not been settled. Up to 75% askarel fuel has been used with most of the operating experience at 50% askarel, 50% diesel fuel by weight.

Liquid PCB wastes are required to be fed to the diesel engine. Destruction efficiencies are said to be greater than 99% based on the whole system i.e. including the scrubber liquor and spent carbon. The developers of this process have opted to maximize the efficiency of the scrubbing and adsorption steps after the diesel and propose to recycle unreacted PCBs back to the front end of the process. The packaged process is said to suitable for mobile operation.

The diesel, scrubber and adsorption configuration are presently being tested in the UK. As of late January 1982 the diesel had 300 hours of operation logged on askarel fuel. On the critical question of toxic by-products the tests have shown that 99.8% of the chlorine fed to the unit has been processed to chloride. The process is designed for liquid waste only; it would require companion technology to handle solid wastes.

Diesel engines have been in operation for a considerable period of time, especially in a "stand-by" mode. Some manufacturers list fuel flexibility as a special advantage in diesel selection. The unit used for cost evaluation was an injection diesel, patented by Detroit Diesel and has been operated on different types of fuel, from kerosene to some No. 1 or No. 2 burner fuels without modification. Manufacturers have not operated diesels with PCB based liquids or mixtures of askarel and fuel oils, and even with a modified injection system of their own design, they may hesitate to warranty such equipment.

The following would likely be required: separate cooling system, fuel pumping system, lubrication systems, manual start with automatic shut-down for cooling system or lubrication oil failure and filtering system for the pumped fuel prior to injection into cylinders.

The diesel engine with generator set and effluent treating equipment is available and all testing in Canada and in the United Kingdom has been done with "Off the shelf" diesel engines, the only modifications found necessary have been to the exhaust control systems. An atomizing air compressor may also be required for this system.

The D & D Group diesel process has received cautious preliminary acceptance in Ontario. The company is planning further testing before seeking regulatory approval for commercial PCB destruction.

The impacts of the diesel process on the operator are likely to be minimal provided routine precautions are taken for the handling of wastes and the operation of such heavy machinery. The public impact of the mobile version of the diesel process would be spread around the various locales where wastes exists. The details of the complete scrubbing/adsorption system are not fully publicized at this time so the full public and natural environment impacts cannot be assessed. It has been noted that the unit is "very self-contained" and "the process is controllable", air and gas flows are low and can be easily trapped and filtered.

References: (Evans, pers. comm. 1982).

4.4 Chemical Processes. Processes based on a specialized chemical reaction to destroy PCBs are fundamentally different from incineration processes. The foregoing processes are quite properly chemical processes but a distinction has been made based largely on the need for high temperature for the incineration to take place. Conversely, these processes are driven by the potential for the chemicals to react rather than the need for high temperature to cause the chemicals to react. Some of the processes produce products at high temperature but that is an effect of the process not a requirement.

The types of process described are:

- Chemical dechlorination;
- Radiant energy processes; and
- (Low) temperature oxidations.

4.4.1 Chemical Dechlorination. All chemical dechlorination processes use chemical reagents to break apart the extremely stable PCB molecule, rearranging it to form other chemical compounds that are considered harmless and environmentally safe. These processes destroy the PCB molecule but do not break down the biphenyl structure of the

molecule. Only the chlorine atoms which give the PCB molecule chemical and biological stability are removed.

Most chemical dechlorination processes use a sodium reagent to strip away the chlorine atoms from the PCB molecule. The wastes generated from the process are sodium chloride and non-halogenated polyphenyls. The exact constitutents of the polyphenyls are often not known but indications show that the sodium chloride and polyphenyls can be disposed of safely.

Most applications involve destruction of PCBs that contaminate otherwise valuable oil. The sodium dechlorination processes can be run at ambient or moderate temperature and although they chemically destroy the PCBs contained in oil they do not destroy the oil itself, therefore, the oil can be recycled for reuse. Sodium dechlorination is limited in that it is only capable of economically dechlorinating PCBs in otherwise valuable oil.

Dechlorination of PCBs by sodium reagents must be conducted in a nitrogen or similar inert atmosphere to prevent excessive reagent consumption and fire hazard due to hydrogen generation on contact with any water or moisture present in the oil.

4.4.1.1 The Goodyear Sodium Naphthalide Process

Head Office: Goodyear Tire and Rubber Co.
1144 East Market St.
Akron, Ohio 44316-0001

The sodium naphthalide process uses a reagent made from sodium and naphthalene to dechlorinate PCBs at ambient temperature. The sodium naphthalide reagent is prepared in a two-step, one-pot procedure. In the first step, metallic sodium is heated to 150-170°C in either heat-transfer or transformer fluid under an inert atmosphere. Cooling the mixture to ambient temperature with stirring forms a finely divided sodium sand. In the second step, a tetrahydrofuran solution of naphthalene is added to the sodium sand in the fluid at ambient temperature forming the soluble greenish-black sodium naphthalide reagent. The reagent is added to the PCB-contaminated oil in an amount sufficient to give a reagent/chlorine ratio of at least 6:1 to 100:1 depending on the type of fluid and its contamination level. The reaction proceeds rapidly at room temperature.

After one hour any excess reagent is slowly water quenched under an inert atmosphere and the quenched fluid is vacuum stripped to recover tetrahydrofuran and

naphthalene for recycle. The residue is subjected to further vacuum distillation, if the treated oil is to be recycled.

The sodium naphthalide dechlorination yields the following products:

- treated oil;
- non-halogenated polyphenyls; and
- sodium chloride.

This dechlorination process can only be used to degrade PCBs in waste oil. It cannot be used to dechlorinate PCBs in water.

The Goodyear process has been teated both in the laboratory and on a commercial scale. In laboratory tests the process was shown to reduce PCB levels from 20 000 ppm to less than 2 ppm. On a commercial scale the treatment was run in carbon steel reactors under an inert nitrogen atmosphere and the process was able to reduce PCB levels from 130 ppm to less than 2 ppm.

Goodyear is not interested in commercially developing the sodium naphthalide technology by itself, so the company has made its information public. Several adaptations of the process have been recently commercialized by other companies.

Although the technology has been tested, further testing is required to determine compliance with PCB regulations and composition of waste by-products.

This batch process is quite sophisticated in design and serves as a good template to those companies modifying the system to obtain EPA approvals.

Based on a flow rate of 910 L/h, the cost of operating this system would be about $0.30/kg of contaminated oil. This cost could be increased to at least $3.00/kg when destroying 10% PCB in oil similar to what the conventional incinerators can handle. The potential for recycle of the treated oil offers additional economic benefits to users of this process.

The sodium naphthalide process is run at ambient temperature in an inert atmosphere with only very small temperature rise occurring during the reaction with lower levels of PCB. Therefore the risks to workers treating PCB-contaminated oil by the sodium naphthalide process would be minimal. One possible worker hazard could come from the generation of hydrogen when unreacted sodium contacts quenching water. This hazard can be controlled by careful, slow addition of quenching water and by maintaining an inert atmosphere in the vessel at all times.

Risk to workers handling the flammable chemicals, such as tetrahydrofuran, used to manufacture the sodium naphthalide reagent would be minimal given that adequate care is taken in handling these chemicals.

The composition of the polyphenyl residue created as a waste by-product of this reaction has not been documented. Therefore incineration of this compound may or may not be hazardous to the public and environment. Further testing must be conducted before this can be determined.

References: (Goodyear Tire and Rubber Co., 1980).

4.4.1.2 Sunohio PCBX

Head Office: Sunohio
1700 Gateway Blvd. S.E.
Canton, Ohio 44707

Contact: Carl Sorenson
(216) 452-0837

The PCBX process is a continuous process that uses a proprietary reagent to strip chlorine atoms from PCB molecules and convert them to metal chlorides and polyphenyl compounds. The PCBX unit is housed on a large tractor/trailer rig. Oil reclaiming equipment and a mobile laboratory are housed in a smaller trailer rig. The twin units are self-contained and can operate from any 460 or 230 volt, 60 hertz power source. The units are so constructed that all process work takes place within spill pans leading to emergency reservoirs capable of holding one hour of full process flow.

The unit is designed to process 2.3 m^3/h of transformer oil at a nominal 2 000 ppm PCB kill. The more PCB the oil contains, the higher the kill. A typical procedure on oil containing 3 000 ppm of PCB would follow this pattern:

First pass reduction to below 1 000 ppm.
Second pass reduction to 100 ppm, more or less.
Third pass reduction to below 2 ppm.

The procedure runs as follows:

- A gas chromatographic analysis of the oil is made to determine PCB content.
- The oil is heated, then goes through a preliminary treatment (data not available) to remove moisture and contaminates.

- The heated oil is admitted to the reactor section and, as it enters, reagent is added consistent with the PCB content of the oil. The mixture reacts as it passes through the reactor section.
- The mixture is centrifuged, filtered three times, and vacuum-degassed.
- The treated oil is returned to the transformer or held in a retention tank. The polyphenyl and inorganic salts residue is solidified and sent to a landfill.

The PCBX process is capable of treating pure PCBs or PCB-contaminated oil. The reagent cannot be used to treat aqueous solutions such as PCB-contaminated ground water. In two tests conducted for the US EPA, the PCBX unit treated a 255 ppm transformer oil and askarel. After treatment (one pass), the transformer oil was tested and contained 1 ppm PCB. Askarel was treated at a rate of 150 mL/min, and a gas chromatograph scan showed that the processing had destroyed the PCBs to a content of 7 ppm in the working fluid. In this test, the working fluid was entering the reactor with 4 400 ppm and emerging at 7 ppm. A test conducted for Region V, US EPA in May, 1982, resulted in transformer oil containing 1 760 ppm PCBs being reduced to the limits of detection in three passes.

The Sunohio PCBX process has been approved in all US EPA Regions, with ppm limitations as shown below:

Region I—No limitation.
Region II—No limitation; 500 ppm limit in reactor loop.
Region III—No limitation; 500 ppm limit in reactor loop.
Region IV—No limitation.
Region V—No limitation; 500 ppm limit in reactor loop.
Region VI—1 000 ppm with 500 ppm limit in reactor loop.
Region VII—10 000 ppm.
Region VIII—2 000 ppm, subject to some volume limitation.
Region IX—No limitation.
Region X—No limitation. 1 500 ppm in reactor loop.

In those Regions where 500 ppm reactor feed limitations have been stipulated, a higher limit will be set upon demonstration of ability. Such a demonstration has been made under the auspices of Sunohio's home Region V, and the upgrading procedure is now in progress.

Sunohio has been operating its process commercially since mid-1981. As of late May, 1982, it reports a roster of 20 large and satisfied customers and nearly 500 000 gallons of contaminated oil having been treated and returned to service free of PCB. There are presently (late May, 1982) five rigs in operation, and the company has the capability of constructing and fielding several new rigs each month.

The PCBX process claims the capability of returning electrical insulating oil to like-new condition, and this claim has been confirmed by exhaustive tests conducted by utility customers, the Electric Power Research Institute, and the Doble Testing Laboratories. This oil quality enables PCBX to be tied directly to a transformer in order to detoxify the transformer as well as the oil. This process, however , does meet the requirements of the PCB regulations.

Little information is forthcoming on the various components of the system and even less on the exact nature of the reagent itself. Sunohio has been notified by the US Patent Office that the claims on its process have been allowed. Identical patent applications are entered in Canada and all other major industrial nations.

This mobile system is available on a quantity/ppm/price basis. The current price for treatment of contaminated oils in the US ranges from $80 to $1.30 per litre for bulk oil, depending upon the degree of contamination. In making price comparisons with other methods of destruction of PCB, the reuse value of the oil is an important factor. Transformers are priced on a per-unit basis and the system is readily available.

The Sunohio unit is completely enclosed and should not impact the workers on-site providing that adequate care in handling wastes and reagents is taken. The units are mobile and can be used to treat PCBs on-site; therefore, the public attitude towards treating PCBs by this method should not be adverse. The process does not yield any air emissions or by-products that would be harmful.

In addition to the environmental stability and full reusability of the treated oil, toxicological studies of the by-products conducted by Sunohio for US EPA revealed no harmful qualities.

Sunohio, the developer of PCBX, is a partnership of Sun Company and Ohio Transformer Corporation.

References: (EPRI, 1981; Annual Conference of the Southern Electric Excharge, 1981; Sworzyn and Ackerman, 1981).

4.4.1.3 Acurex Process

Head Office: Acurex Waste Technologies, Inc.
485 Clyde Avenue
Mountain View, California 94042

General Manager: Don Fraser,
(415) 964-3200

Research Manager: Leo Weitzman
Acurex Waste Technologies, Inc.
074 Beechmont Avenue
Cincinnati, OH 45230
(513) 474-4420

The Acurex dechlorination process is a modification of the original Goodyear sodium naphthalide process. The Acurex system uses a mobile batch process for treating PCBs and PCB-contaminated oil with a sodium reagent at a rate of 0.9 m^3/h.

The company has changed the original sodium naphthalide reagent by replacing naphthalene, a priority pollutant, with another constituent (proprietary) which is a non-priority pollutant. The PCBs or PCB-contaminated transformer oil enters the system at one end where it is filtered and batch sized. As the oil is transferred downstream, the sodium reagent is added and the mixture is allowed to react. After complete destruction of PCBs is shown by gas chromatographic analysis of a batch sample, the excess reagent is quenched. The PCB-free oil is then filtered and returned for reprocessing or for use as a fuel oil. The Acurex process is run under an inert atmosphere at ambient temperature with slight excess amounts of sodium reagent.

It is stated in manufacturers' literature that the Acurex process produces treated oil containing no PCBs and a sodium hydroxide effluent. Although no specific reference is made concerning the fate of the chlorine in the PCB molecule, it is likely that it leaves the process as NaCl in the NaOH effluent. The only air emissions released are small amounts of nitrogen and hydrogen containing less than 1 g/min total hydrocarbon, no measurable PCBs and no particulates.

Waste transformer oil containing up to 1062 ppm PCBs can be treated using the Acurex system. In September 1981 tests were conducted for the EPA. Oil containing up to 1062 ppm PCBs was treated and the PCBs were completely destroyed. The process routinely reduces the PCB level to <2 ppm. As in all sodium processes the Acurex system cannot be used to treat PCBs in aqueous solution.

The Acurex system was developed in 1980 and Acurex currently has one mobile PCB destruction unit in operation. They expect to have 6-12 units in operation by the end of 1982 depending on user demand. The mobile unit has been thoroughly tested for capability in destroying PCBs and is pending EPA approval before commercial development of the process.

This process lends itself well to a micro-processing control system. Monitoring of the contaminated oil through each stage can be attained, while at the same time, optimizing the flow.

The cost of PCB destruction using this process would be approximately $2.40/gallon of oil treated. This is approximately $0.70 (US) per kilogram of oil treated. The system is designed to destroy PCBs up to a concentration of 1000 pm in contaminated oil, well below capabilities of other technologies which handle 10 per cent or higher PCB concentrations. Oils with PCB concentrations of 10 000 ppm have been treated using this process and it is currently being demonstrated at this level.

According to all available test data, the Acurex process gives off no effluents, or by-products that would be unduly hazardous to workers, the public, or the environment. Proper control of the unit and testing of the products and by-products must be maintained to ensure worker safety. The impact of the Acurex system on the public is diminished by the fact that the unit is mobile. PCB-contaminated fluid need not be transported off-site, thus diminishing the possibility of spills, and the problem of having a permanent facility which could be a hazard to a specific area is avoided.

The Acurex mobile PCB destruction process is currently approved in three EPA regions to destroy PCB transformer oil containing up to 1000 ppm PCB and the company is expecting approval from the other regions at any time.

References: (Weitzman, 1982; Miille, 1981; Acurex Corp., 1981).

4.4.1.4 PPM Process

Head Office: PPM Incorporated
8220 Travis
Overland Park, Kansas 66204

Contact: Dennis Tapsak
(913) 648-0448

PPM Incorporated has developed a mobile chemical process for destroying

PCBs using a sodium reagent. The unit is hauled on a tractor trailer to the site of the PCB-contaminated oil. The proprietary sodium reagent is added to the contaminated oil and left to react. There is no adverse environmental impact resulting from the operation of the PPM, Inc. mobile PCB decontamination process. The unit emits no effluent, and emissions are limited to nitrogen and a small amount of hydrogen. The solid polymer which is filtered out of the oil by our process is a regulated substance in the United States, but does not contain PCBs and can be readily disposed. We generate about one 55 gallon barrel of polymer (US gallons) for approximately every 40 000 L of oil treated.

Testing conducted for the US EPA indicated acceptable destruction efficiencies. In the testing 70 000 L of oil contaminated with 200 ppm PCB were treated with the sodium reagent. After reaction no PCBs were detectable in the treated oil.

Insufficient information was available on the PPM process to give an estimate of capital and operating costs. It may be considered that these costs would be in the same range as the other sodium processes.

The PPM process has currently been approved in EPA Regions I, IV and VIII to destroy oils contaminated with up to 10 000 ppm PCB and PPM expect to have approval in all EPA regions by this summer. PPM has one unit in operation as of January 1982. This process is being considered for application in Canada.

References: (Manufacturer's literature; Tapsak, pers. comm., 1982).

4.4.1.5 NaPEG Process

Head Office: Franklin Institute Inc.
Research Laboratories
The Benjamin Franklin Parkway
Philadelphia, Pa. 19103

Contact: Dr. Steve Osborn,
Technical Manager
(215) 448-1297

The NaPEG PCB destruction methods uses a chemically modified sodium polyethylene glycol complex as its reagent. The composition of the reagent can be varied depending on the type of polyethylene glycol (PEG) that is used. PEG400, i.e. polyethylene glycol having a molecular weight of approximately 400 is normally combined with the sodium to form NaPEG400. Sodium polyethylene glycol is made by adding sodium

to polyethylene glycol at an elevated temperature. The amber sodium polyethylene glycol is produced almost immediately with the evolution of heat and hydrogen.

The Franklin Institute manufactures the NaPEG at their facility in Philadelphia, and then ships the reagent to a location where PCBs are to be destroyed. When the reagent is manufactured, it is stable for more than 2 years; it is not sensitive to small quantities of air or water, and contains no metallic sodium. PCB can be destroyed using the NaPEG system in a mobile, or a permanent facility. The NaPEG reagent is added to the PCB-contaminated material on a batch basis at a temperature ranging from ambient to 150°C. The mixture is left to react; the reaction by-products are removed; and any excess reagent is neutralized after the PCBs are shown to be destroyed. The reaction by-products are sodium chloride; nontoxic organic compounds; and decontaminated material.

The NaPEG reagent can be used to decontaminate PCB-containing oils. Use of the reagent to decontaminate solids, including soils, is presently being investigated under grants from the US EPA. The presence of water and air in small amounts does not appear to hinder the reaction.

The process is simple to run, and users are expected to be able to process their own oils for cleanup and reclamation on-site, using relatively simple equipment. A batch plant can be constructed from components that are normally available with some specially purchased equipment such as a stirrer, a controller, or a special duty pump. The Franklin Institute has constructed one process demonstration unit which is currently being used to test the process for the US EPA. In EPA monitored tests, contaminated oils containing up to 400 ppm of PCBs have been successfully treated.

The technology involved is not complex in nature, and would be relatively easy to operate. No such system is presently in operation to destroy PCBs. The process appears to comply with all of the current EPA regulations, including emissions from the process, which are below the limits of detectability.

Little information is available on the technology as far as flow rates, PCB concentrations, or costs are concerned. However, the costs are currently estimated at about $1.50/kg of PCB-contaminated liquid treated.

The process involves equipment normally available for batch operations: tanks, transfer pumps, mixing chambers, diaphragm control valves, piping construction of compatible material, etc.

The NaPEG reagent, after it has been produced, is not hazardous to persons using it, although it should be handled with the same caution given all potentially dangerous chemicals.

The public at large and the environment are not overly affected by the NaPEG system although the exact composition of the organic compound forms as by-product is not known.

The NaPEG process is currently being demonstrated to the US EPA Region III and is under review for approval. Final approval is expected during the early 3rd quarter of 1982.

References: (EPRI, 1981; Franklin Inst. Research, Lab. Inc.; Pytlewski et al.)

4.4.1.6 Environmental International Process

Head Office: Environmental International Inc.
912 Scott
Kansas City, Kansas 66105

Contact: William McGaugh, Senior Vice-President
(913) 281-0057

Environmental International Inc., has devised a process for treating waste capacitors and transformer oils contaminated with PCBs that can be used as an alternative to incineration. The process involves the mechanical rinsing of the capacitors to remove all PCBs. The capacitors are taken apart and thoroughly rinsed and cleaned. The metal salvaged is sold as scrap. The PCB fluid is removed to a storage tank for treatment.

The PCBs, removed from the capacitors, and any transformer oil contaminated with 570 000 ppm PCBs are treated chemically with a proprietary reagent. The treated oil is recycled and the waste by-products (which are considered non toxic) are landfilled.

The Environmental International process is capable of treating "out of service" capacitors at a rate of 100/shift as well as contaminated transformer oil. The chemical treatment process is not presently mobile, but the company is considering developing one if they should find a demand for such a process.

Environmental International is approved to accept PCB-contaminated capacitors and do so at a cost of $1.10/kg, for non-leaking capacitors crated in wood crates, or $1.65/kg for capacitors in steel drums (these do not include transportation costs). On receipt of the capacitors, the company takes over legal responsibility for the proper

treatment and/or disposal of the PCBs and capacitor shell. The crated capacitors are kept in an on-site storage facility until they can be treated.

The process has obtained a 3 year approval in EPA Region VII, and the company has approval to accept PCBs from any location as long as they are treated at their Kansas City site.

Reference: (McGaugh, pers. comm., 1982).

4.4.1.7 Other Sodium Type Dechlorination Processes.*

Company Name	Process Type	Status
Life Enterprises Inc., Barto, PA	- modified sodium naphthalide process	- review of process by EPA - region III has been requested but no follow-up has been made
General Electric Corp., Philadelphia, PA	- standard sodium process - exact constituents of reagent are confidential	- approved to conduct a test of the process at the company's leisure in EPA Region III
British Columbia Hydro	- sodium metal dechlorination process	- in the process of researching scale-up potential of the lab. process
Ontario Hydro	- sodium metal dechlorination process	- pilot plant scale testing
PCB Destruction Co. Kansas City, MO	- sodium type dechlorination process	- testing of process done for EAP Region VII; results showed problems with process
PCB Eliminators Kansas City, MO	- chemical dechlorination	- under review by EPA Region VII
Radium Petroleum Kansas City, MO	- chemical dechlorination waste oils	- bench scale demonstration completed for EPA with satisfactory results; process under review

* A number of other sodium dechlorination processes were identified. Most of these processes are at an early stage of development and little new information was forthcoming over that found for those already reviewed. The processes follow, for completeness.

4.4.2 Radiant Energy Processes. The promotion of chemical reaction, and therefore destruction of PCB can take place by the application of radiant energy. A number of processes are being evaluated which are based fundamentally on some radiative process that initiates the process reaction. In these radiative processes energy either interacts directly with the PCB molecule promoting its reaction, or interacts with an intermediate species which subsequently attacks the PCB molecule. In both cases, the question of temperature becomes relatively unimportant; these processes operate from within a few degress of room temperature to temperatures that reduce the waste to basic molecular fractions.

4.4.2.1 Thagard High Temperature Fluid Wall Reactor

Head Office: Thagard Research Corporation
2712 Kelvin Avenue
Irvine, California 92714

Contact: E. Matovich
(714) 556-4470

The High Temperature Fluid Wall (HTFW) reactor is a radiant energy process, because the driving force for the reactor is a series of carbon rods electrically heated to high temperature such that they radiate (infrared) radiation. This radiation is focused in a manner described below on waste material contained in a pourous tube. The tube material, which is transparent to the IR radiation, is protected from the heated waste by a fluid curtain of gas that is caused to flow over its surface.

The reactor configuration is given in Figure 10. The reactor consists of a jacketed insultated cylinder typically 30 cm in diameter. Inside the cylinder six carbon electrodes are arranged as shown in Figure 11. When electrically heated to about 2000°C, these electrodes emit infrared radiation. The inside walls of the reactor are lined with insulation and a carbon radiation heat shield which reflects the energy back towards the centre of the reactor.

A pourous tube made of a ceramic material that is transparent to the IR radiation runs down the centre of the cylinder. Inside this cylinder, energy is absorbed by a slurry of carbon particles in the waste. Absorbed energy creates high surface temperatures which break the waste molecules into simple molecular fragments, in the case of PCBs; HCl, CO, CO_2, CH_4 and H_2 (note: water may have to be added to provide enough hydrogen and oxygen to produce gaseous products). The whole inside of the

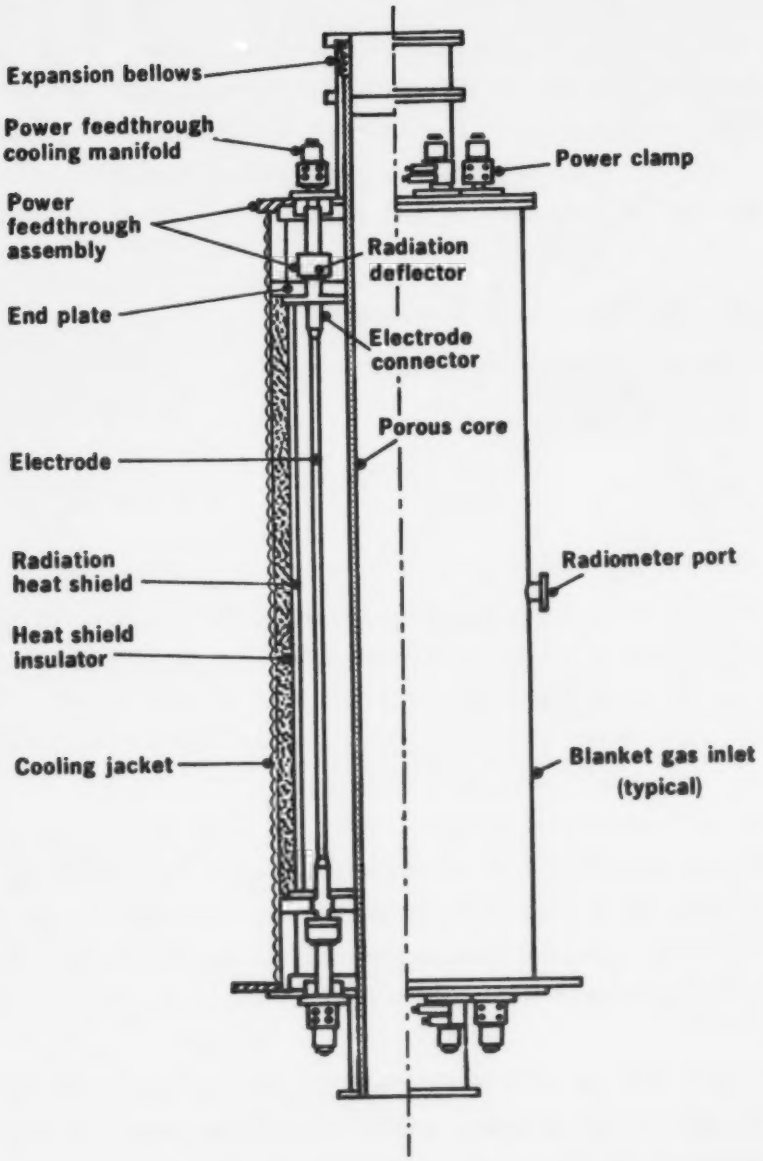

FIGURE 10 VERTICAL CROSS-SECTION OF A TYPICAL FLUID-WALL REACTOR (Thagard Research Corp., 1981)

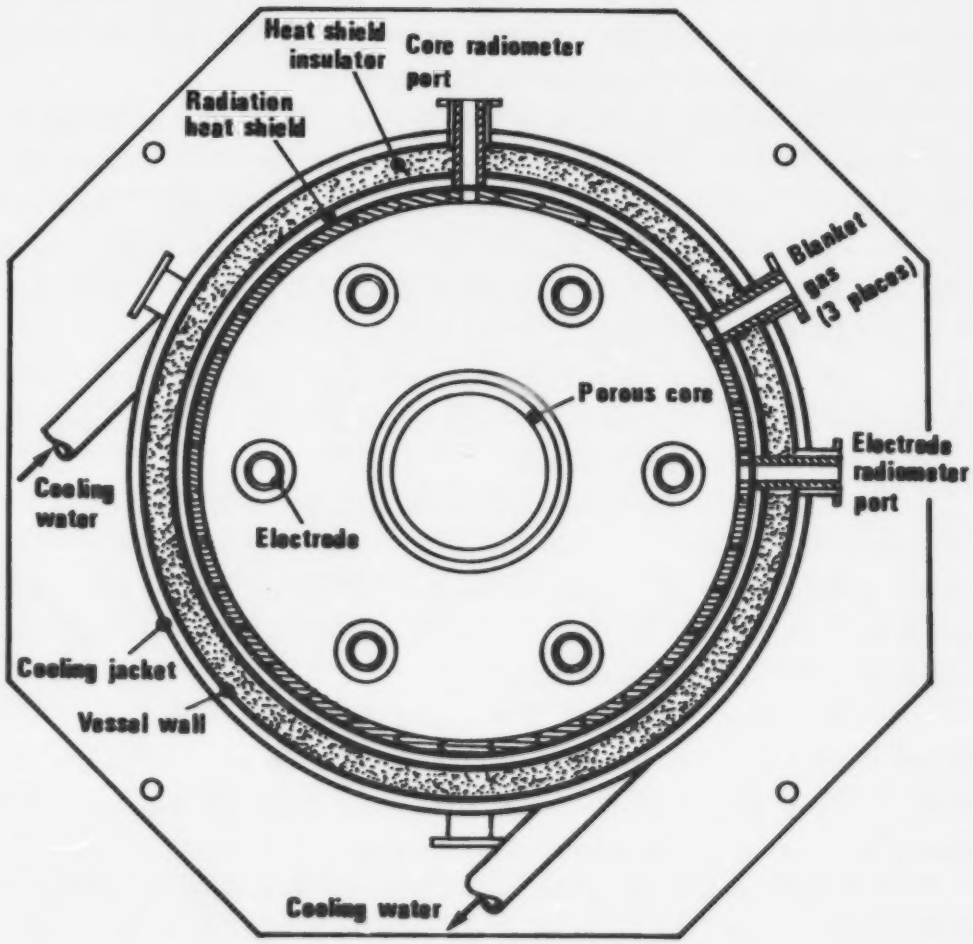

FIGURE 11 HORIZONTAL CROSS-SECTION OF A TYPICAL FLUID-WALL REACTOR (Thagard Research Corp., 1981)

reactor is bathed in nitrogen which is drawn through the porous central reaction tube to form a fluid film on the inside of the reaction tube to prevent contact from the heated waste.

This technology is in relatively early stages of development. A 30 cm by 9 m reactor has been tested on hexachlorobenzene; tests on PCBs under US EPA auspices are planned for later in 1982. The company has spent some five years developing the reactor to this stage and demonstrating process chemistry.

The reactor will likely be able to handle both solids and liquids provided solid PCB waste is shredded finely enough. The concept at this time is to add lime and silica to neutralize HCl produced and immobilize ash in a vitreous state. Reactor by-products from this high temperature pyrolysis will be simple gas molecules which can be burned to innocuous products. The company feels that waste throughputs of 130-180 Mg per day can be achieved with this technology.

As previously mentioned, this technology is still in early stages of development. Although previously tested on many waste products including a surrogate for PCB, a test on PCB material is still pending.

Capital and operating costs, and in turn unit destruction costs, are difficult to estimate and cannot be included in this study. Capital investment in a large air pollution control system could be minimized because off gases are in the low to moderate temperature range; however, the high level of electrical energy input required would contribute significantly to operating costs.

Reactors of this type, with cylindrical core diameters of up to 120 cm, are presently being scaled to treat 150-250 Mg/day of toxic waste. Apart from the reactor itself, ancillary equipment for larger sized units is readily available. Cooling water pumps, for instance, can be purchased off the shelf.

Final impacts on natural and worker environments will only be defined after scale-up and testing. The reaction of the US EPA is positive as they will be supporting additional waste testing in the Spring of 1982.

References: (Thagard Research Corp., 1981; Oppelt, 1981).

4.4.2.2 Plasma Arc Pyrolysis Process

Royal Military College
Department of Civil Engineering
Kingston, Ontario

Contact: Dr. T.G. Barton
(613) 545-7395

The Plasma Arc Pyrolysis Process makes use of the energy in ionized gas molecules to cause the dissociation of PCB molecules. The ionized gas molecules exist in a plasma created by the discharge of electrical current through a collimated vortex of low pressure gas. As these ionized gas molecules decay they transfer energy to the PCB molecule in a number of ways. The ultraviolet radiation given off as the ionized species decays is thought to be one of the major energy transfer mechanisms, thus this process is included as a radiant energy process.

The major innovative feature of the Plasma Arc Pyrolysis Process is the plasma generator called the plasma torch. This device produces a toroidal vortex of low pressure gas through which electrical current is passed, creating the plasma. The torch acts as one electrode, and a hearth in the bottom of the reactor acts as the other electrode, Figure 12. The power supplied to the torch is capable of delivering 1000 V at up to 300 A. Centreline temperatures equivalent to 50 000 K are achieved in the plasma.

Gas volumes supplied to the torch are small fractions (>5%) of the gas volume required if the waste were to be combusted. The gas composition is not critical. The waste PCBs are pyrolyzed with the main products being CO, CO_2, HCl, H_2 and H_2O. Typical energy requirements are: 1.26 MJ/kg of PCB waste producing outlet temperatures in the range of 1110 K.

At present, tests are being run to determine the destruction efficiency of PCBs in the reactor. The PCBs are injected as a stream directed at the reactor hearth. PCB destruction efficiencies in excess of 99% were demonstrated in previous preliminary work.

Destruction of solid waste awaits further testing although the process itself was originally designed and tested on non-PCB solid wastes. Processing rates will fall in the 100-1000 kg/h range.

The capital costs involved for a reactor capable of destroying 15 kg/min of PCB fluid are estimated to be approximately $700 000 for a system that includes a 600 kW

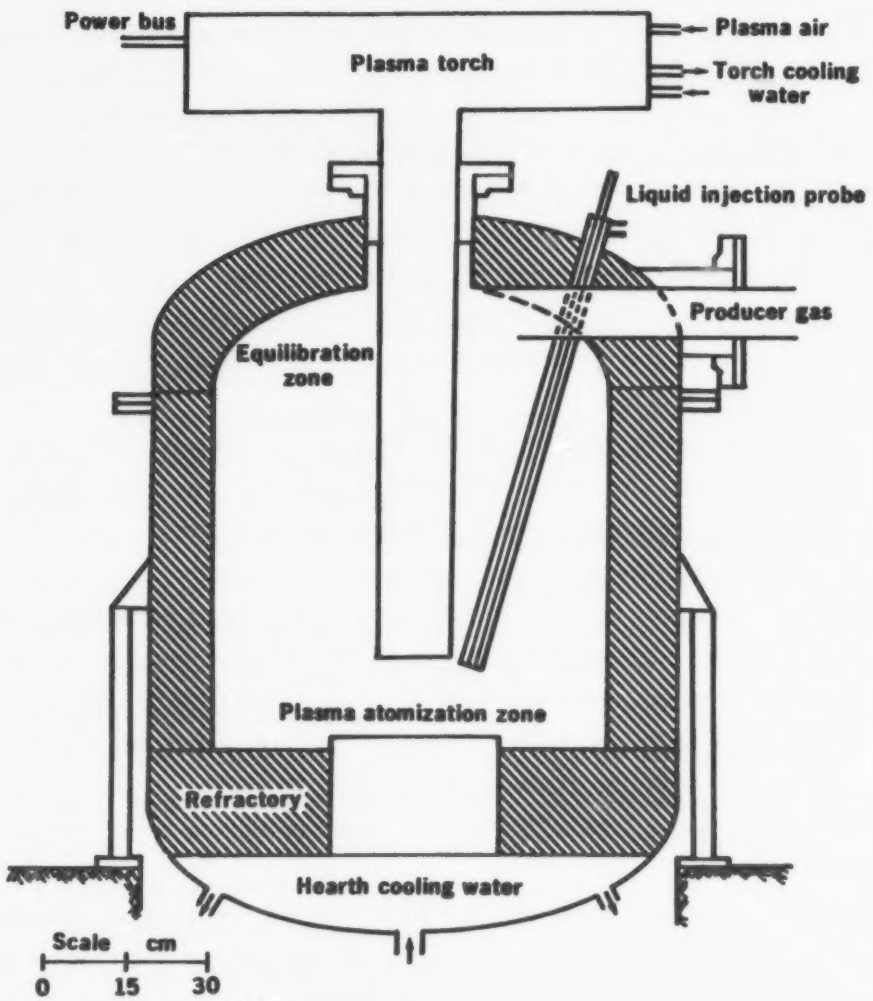

FIGURE 12 REACTION VESSEL SCHEMATIC (Royal Military College, March, 1982).

power feed; scrubber, air compressor, water cooling system; water treatment system, feed system, building and laboratory.

Supervisory and operating personnel would be the main reason for high operating costs, likely in the neighbourhood of $1 200 000 per year including cost of capital investment. This figure is based on a 4 shift, 7 day week schedule with a standard receiving and storage schedule of 40 hours. Unit cost of destruction over a one year period would be $0.26/kg.

Components of the system are readily available, with the exception of land which is not included in the aforementioned capital cost.

The unit costs would be reduced if destruction were performed by a contractor destroying PCBs on-site with plasma reactor and accessories mounted on highway trailers. To increase the capacity of such a system, modules of the same capacity (15 kg/min) could be run side by side rather than increasing the capacity of a single unit.

Environmental impacts are likely to be slight. By-product gases can be flared and solid residues are likely to be inert inorganics. Occupational risks are those of any hazardous materials handling facility.

Results from PCB destruction tests submitted to regulatory officials in Ontario for review in March 1982 are available. "Tests on Aroclor and Askarel with a chlorine content up to 58 percent, show destruction efficiencies in excess of 99.9999 percent with no by-product dioxin detected. These results were corroborated by Laboratory Services of Environmental Canada."

References: (Dobson, 1980; EPRI, 1981).

4.4.2.3 Catalyzed Microwave Process

Queen's University
Department of Chemistry
Kingston, Ontario

Contact: Dr. J. Wan
(613) 547-6180

The catalyzed microwave process for PCB destruction makes use of short duration high energy pulses of microwave energy to activate oxygen and PCB molecules at a metal surface. The molecules react to product CO_2, H_2O and a metal chloride.

The key to the process is the metal catalysts. The process is being patented so the exact nature of the catalysts was not disclosed. The catalysts are suspended in a fluid bed fluidized by recirculating pure oxygen or air (two atmospheres). PCBs are introduced into the system and largely remain coating the catalyst surface. Short pulses (<1 seconds) of high energy microwaves (>2 kW) are focused on the catalyst bed. The energy is absorbed at the surface and is transferred to adsorbed O_2 and PCB molecules, activating them, and promoting their reaction to the products. There is a pause of 10-15 seconds between pulses so the entire process temperature rises only 10-15°C above ambient. The energy usage was said to be 50% efficient.

The process is in the laboratory evaluation stage. The PCB destruction efficiency observed at this time is >90% based on recovered chloride. The process will be developed further at Queen's University to refine the engineering details. The technology is being developed to recover hydrocarbons from tar sands; as such the engineered units will have to handle solids. Thus the potential for this process to treat solid PCB wastes will be seriously considered.

As this is a very new technology with little work done outside of laboratory studies it is too early to assess environmental impacts and determine regulatory views. Similarly cost and engineering considerations remain to be developed through pilot scale studies.

References: (Spencer, 1982; Wan, pers. comm., 1982).

4.4.2.4 Microwave Plasma Process

Chemistry Research
Lockheed Palo Alto Research
Laboratory
Orgn. 52-35, Bldg. 204
3251 Hanover Street
Palo Alto, California 94304

Contact: Dr. E.L. Littauer, Manager
(415) 493-4411

Lockheed has been developing the microwave plasma technology with funding support from the US EPA and the Canadian Electrical Association but the recent funding cut backs have affected these studies. Lockheed have stopped work on the process and do not intend to pursue it on their own.

The Lockheed Microwave Plasma process has been widely discussed in the PCB destruction field. As a result this short note is included for completeness.

Their process involves continuous irradiation and activation of low pressure oxygen (0.1 atm) with microwave energy. PCBs introduced into the radiation zone combine with the active oxygen to produce CO_2, HCl and H_2O.

4.4.2.5 Light Activated Reduction of Chemicals (LARC) Process

Atlantic Research Corporation
Alexandria, Virginia

Contact: Judith F. Kitchens
Manager Environmental Sciences
and Engineering Division

Light Activated Reduction of Chemicals (LARC) is a patented (U.S. Pat. 4 144 152) process for the destruction of halogenated organics by ultraviolet light. The process uses UV light in the 1850-4000 Å region in combination with hydrogen gas to affect the dehalogenation of the chlorinated organic molecules.

Two LARC reactors were used in research; a single lamp tube reactor and a 64-lamp pilot unit. Both reactors contain low pressure UV lamps with 95% of their output at 2537 Å. The hydrogen gas is introduced into the reactor via 2.0 μ fritted stainless steel spargers.

TABLE 8 PERTINENT REACTOR PARAMETERS

	Tube Unit	Pilot Unit
Number of Lamps	1	64
Capacity	600 mL	40 L
Light Path Length	5.33 mm	6.35 mm
Radiant Energy at Lamp Sleeve Surface	36 300 $\mu W/cm^2$	29 400 $\mu W/cm^2$
Hydrogen Flow Rate	0.26 L/min	1.9 L/min
Type of Operation	- flow through or batch recycle	- flow through or batch recycle

The ultraviolet light initiates a photochemical process by homolytic cleavage of the carbon-chlorine bond in the PCB molecule. Optimal conditions to maximize this cleavage and the resultant formation of a carbon-hydrogen bond include the use of shorter wavelength UV, higher temperature and increased hydrogen flow and turbulance. PCBs are fed to the reactor and held for a >20 minute reaction time. The fluid is then analyzed by gas chromatography to determine PCB degradation. The reaction continues until the required dechlorination is met.

The LARC is capable of dechlorinating PCBs, PCB-contaminated waste oil and Aroclors extracted from soil by isopropanol. Degradation products of the LARC process include hydrogen chloride and biphenyl. Large concentrations of biphenyl appear to inhibit the reaction; however, both the hydrogen chloride and biphenyl can be removed by distillation.

In a test involving Aroclor 1254 and 1260 a trend of increasing initial degradation rate with increased chlorination was shown. The pilot unit demonstrated increased degradation over the single lamp reactor due to higher light flux and optimized temperature and flow pattern. These initial rates dropped off over the reaction period due to the formation of biphenyl which competed for the UV. In a commercial process the biphenyl would have to be removed to improve reaction efficiency to greater than the 85% destruction shown in these tests. The tests showed that the maximum initial concentration of PCBs that can be destroyed by this method is 3500 ppm.

Before treatment of PCB-contaminated waste oils can be affected by the LARC process the UV-absorbing oil degradation products in the fluid must be removed. Fuller's Earth or some other chromatographic medium may be used for this purpose. A diluent must then be added to lower the oil viscosity aiding hydrogen gas dispersion in the oil.

Tests were conducted using fluid containing 1000-2000 ppm PCB. All diluents resulted in faster PCB destruction than for PCBs in oil alone. An oil/tetrahydrofuran/isopropanol diluent mixture resulted in the highest initial degradation rate.

The pilot facility is still in its middle stages of development and more testing and feasibility studies are required prior to full scale up. A low to middle level of operator skill can be anticipated due to the simple batch nature of this process, although this technology could become quite sophisticated technically if the operation was continuous.

Costing figures could only be estimated as process descriptions were sketchy and not well defined. Tankage, pumps, conveyor systems, mixers, hopper bins, a distillation column and the reactor itself can be expected to cost just over $1 000 000 if the pilot plant was duplicated for production destruction of PCBs. This figure would include associated piping and instrumentation but no land costs.

Operating costs, again an estimate, would be approximately $1 200 000. Operation at 85% utilization, 24 h/day and 310 days a year, would give an estimated unit cost of $1.38/kg of PCB destroyed.

Further analysis of the LARC process on a commercial scale must be made before an environmental impact assessment can be made.

The process has been patented in the United States and the company is testing on a pilot scale. The process is not yet available commercially and status with the US EPA is unknown.

References: (Kitchens et al., EPRI, 1981).

4.4.2.6 Other UV Light Degradation Techniques. Several other companies have attempted to use UV light as a method for photochemically dechlorinating PCBs. In all cases it was found that UV alone was not efficient enough to completely dechlorinate PCBs to meet government requirements.

Vertac Chemical Company, Memphis, Tennessee. Vertac has developed an ultraviolet photolysis process for destroying 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) contaminated wastes. They found that this process can also be used to dechlorinate PCBs. Work on the process has stopped, however, pending a review of an EPA order to stop all work and research into the process.

References: (EPA, 1982; Weitzman and Pruce, 1981).

Pure Water Systems Inc.

Pure Water Systems Inc.
4 Edison Place
Fairfield, N.J. 07006

Contact: Tom Creeden
(201) 575-8750

Pure Water Systems (PWS) recently completed laboratory tests which suggest that their ultraviolet purification system may provide an efficient and inexpensive way to

degrade PCBs. PWS has patented treatment equipment which maximizes the intensity of the UV source using thin films and automatic cleaning devices on the UV lamps.

By using small volumes of contaminated material and repeated recycling through the system, the process can dehalogenate a 1000 ppm PCB solution to <50 ppm. The waste by-product produced is biphenyl and 380 L of PCB-contaminated liquid can be treated for <$10.

The company plans to mount the system on a mobile platform to preclude transport of PCBs to the main PWS facility.

Reference: (Hazardous Materials Intelligence Report, 1982).

The Oxyphoton Process

Bioferm International
Medford Medical Bldg.,
Stokes Road
Medford, New Jersey 08055.

Contact: Howard E. Worne
(609) 953-1125

In the Oxyphoton® system PCB-contaminated waste liquid containing a special catalyst is spray-atomized and premixed under pressure with an oxygen stream containing 1-2% ozone. It then passes through a high-intensity, 2300 to 2750Å, UV plasma. The photo-oxidation catalyst causes a series of chemical reactions and breaks the PCB into low molecular weight fragments. As a final step, the effluent is adjusted to pH 6.8-7.2 It is then fed to a normal biological waste treatment facility for final disposal.

The exact stage of development of the Oxyphoton® process is not known, nor is the concentration of PCBs, in a waste oil solution which would be treatable.

References: (Worne Biochemicals Inc.; Eco/log Week, 1981).

4.4.3 Oxidation Processes. The oxidation of PCBs to CO_2, H_2O and HCl is the process involved in conventional and novel incineration. Oxidation at lower temperature does take place to a greater or lesser extent depending on the temperature, solubility of PCB in solvent and the solubility of the oxidant.

Given the chemical stability of PCB it is not surprising that the solvent selection is limited to water and the oxidant to oxygen. There has been some work in Europe on the use of chlorine as an oxidant (producing by-product CCl_4) but this concept has apparently not been applied in North America.

As the processes go to lower operating temperatures it becomes more difficult to destroy PCBs, catalysts are required or protracted residence times are needed. One process that is reported to have worked most successfully is described in detail; the Modar Inc., supercritical water process. The others are described in general. The costs are assumed to be similar among these processes. The cost advantage of complete destruction and short residence time offered by Modar may be offset by the need for more robust process equipment.

4.4.3.1 Modar Supercritical Water Process

Head Office: Modar Incorporated
14 Tech Circle
Natick, MA 01760

Contact: Michael Modell
(617) 655-7741

The MODAR Supercritical Water Process (SWP) makes use of air or oxygen as oxidant in an aqueous medium at temperatures above the critical temperature of water, 374°C, and pressures above the critical pressure of water, 218 atmospheres. Under these conditions hydrocarbons and oxygen are almost completely miscible with water and inorganics are generally insoluble.

The MODAR concept, which has only been tested in the laboratory, involves slurrying the waste and pressurizing it for eduction into the SWP reactor (see Figure 13). The heat generated during oxidation provides motive power to induct waste into the reactor and provide steam to assist the feed and oxidant pressurization. Although not shown on this diagram, a base is added to the system so that anions (such as Cl, P, S) can be reacted to salts and rejected in a salt separator. Residence times of less than 1 minute in the oxidizer are reported with destruction efficiencies of greater than 99.99% for typical hydrocarbons.

As indicated, this process has only been demonstrated in the laboratory at a scale of 4 L/day organic throughput. However, a 190 L/day pilot reactor is being developed jointly by MODAR for field tests with actual wastes.

Since the process is still in the bench scale stage, costing of a reasonable scale plant is difficult. For a facility, with a capacity of 10 000 L/day of organic material initial estimates are that minimum capital cost would be approximately $5 200 000 (US). Unit processing costs would be $0.13 - 0.53 minimum for each kg of organic liquid

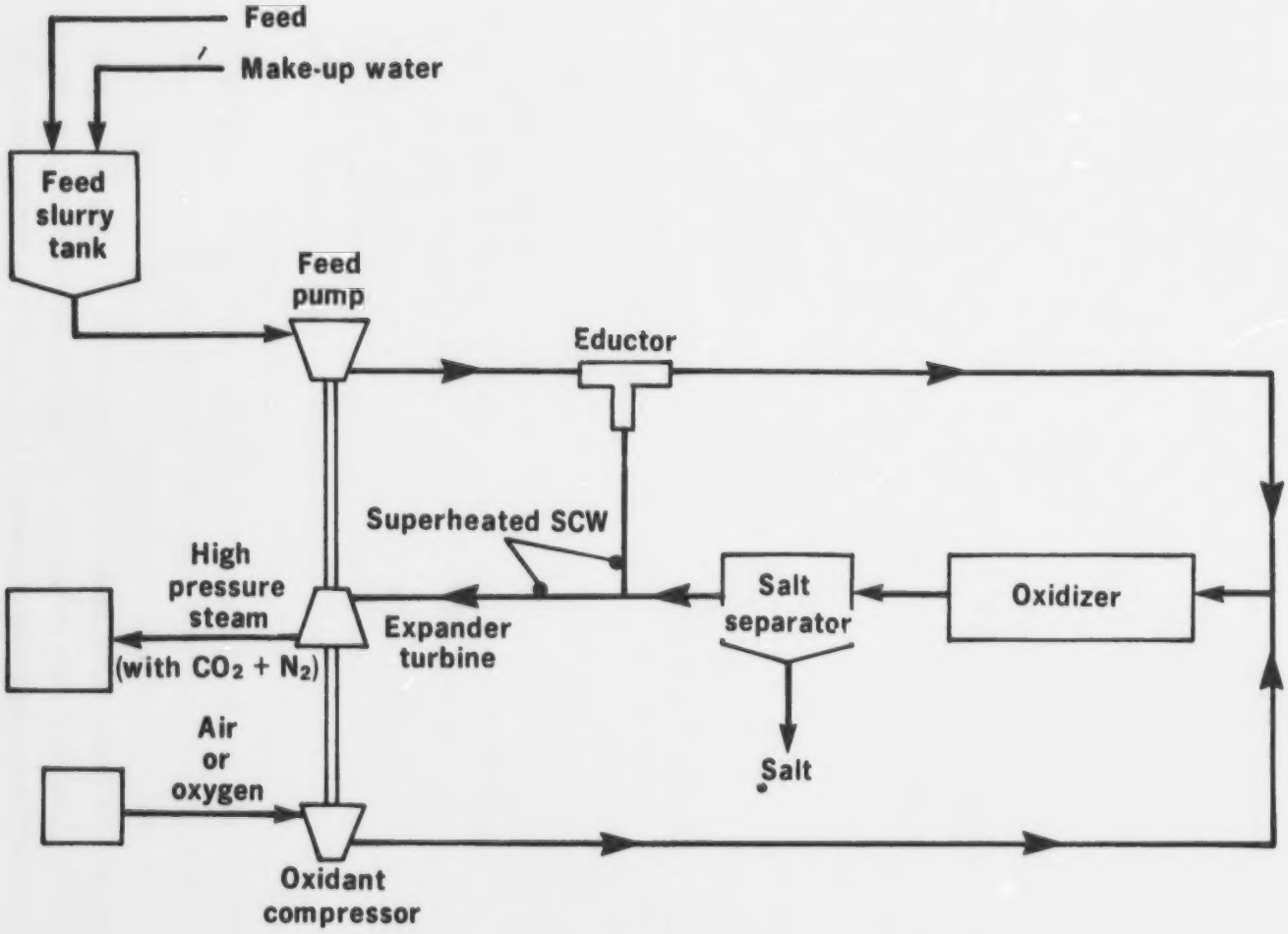

FIGURE 13 SCHEMATIC DIAGRAM OF THE MODAR SUPERCRITICAL WATER PROCESS (Oppelt, 1981)

destroyed in the reactor. This process as it pertains to the destruction of hazardous and toxic wastes is in its early development stage; its reliability at a reasonable scale remains to be demonstrated. The technology has been operated at bench scale for the past two years and will undergo pilot plant tests in 1982-83.

The impacts of this technology await further development. However, a significant environmental advantage claimed for the process is that process effluents are minimized; only salt, H_2O, CO_2 and a small portion of feed organic exit the oxidizer. The salts have been washed in the supercritical fluid and oxygen and should be disposable by ordinary means. (Fluid stream from the oxidizer contains N_2 as well if air has been used as the oxidant). The feed organic material in the output steam stream can be managed to very low levels by control of reaction conditions in the oxidizer. Relatively refractory organics such as PCBs and other chlorinated hydrocarbon compounds have been destroyed with efficiencies in the range 99.99 - 99.999%, with oxidizer residence times of 1 minute or less.

Reference: (Oppelt, 1981).

4.4.3.2 Wet Oxidation, WETOX®, Process

WetCom Engineering Limited
222 Midwest Road
Scarborough, Ontario
M1P 3A9

Contact: Paul Gooderham
(416) 759-8595

The WETOX® process employs air oxidation in water at moderate temperatures in the range of 150 to 250°C, so-called wet oxidation. Wastes are oxidized to water, CO_2 and short chain organic acids and alcohols. The process features a horizontal multi-compartmented agitated cascading reactor. Heat is recovered from the waste oxidation and is recycled for reuse.

This technology is very well developed and has been used in various modifications (e.g. Zimpro Process) for a number of years. The wastes treated include most complex organic compounds including difficult to treat chlorinated hydrocarbons. The process was developed at Michigan Technological University in Hougton, Michigan and at Ontario Research Foundation who have produced a mobile WETOX® process in a single van-truck. WETOX® was being evaluated for PCB destruction by the Ontario Research Foundation. The results obtained were not encouraging; destruction efficiency was in the

50-70% range. Long batch times and high temperatures over 250°C that taxed the ORF test equipment. The work was abandoned as a result of unrelated local political problems. Michigan Technological University on the other hand has tested the process on PCB's at higher test temperatures with some encouraging results.

Reference: (Johnston and WetCom Engineering).

4.4.3.3 IT Enviroscience, Catalyzed Wet Oxidation

Head Office: IT Enviroscience
9041 Executive Park Drive
Knoxville, TN 37919

Contact: J. Exner
(615) 690-3211

IT Enviroscience has developed a catalyzed wet oxidation process utilizing lower temperatures in a different reactor configuration, than the WETOX® process. The process has been developed on the mini-plant scale and uses batch processing or a combination of continous and batch processing. Destruction efficiencies are higher than WETOX® and >99% PCB destruction has been achieved in the mini-plant.

An adequate destruction rate was demonstrated such that a total waste processing cost of $4-5/kg (US, 1979, capital plus operating) was suggested in a brief study commissioned by Ontario Hydro.

Reference: (L.E. Johnston and IT Enviroscience).

4.5 Physical/Chemical Processes. Unlike all of the other process types considered previously, physical/chemical processes for handling PCBs are not treatment or destruction. In all of these processes, PCBs are extracted from transformers and replaced with another fluid. This does not help get rid of the PCB problem it just changes its location. The PCBs must still be treated or disposed of by some appropriate means.

These "extraction" processes use known and well tested chemical or physical methods for extraction of organic compound from another medium. Methods can range from the very simple physical process of thoroughly draining a PCB-filled transformer and replacing with an non-PCB-containing dielectric fluid to the more complex chemical processes such as distillation of the PCB from the transformer fluid or shredded capacitor.

There are over a hundred companies in the United States and four or five in Canada who are in the business of extracting PCB-contaminated fluids from transformers. Many of these are in the transformer service or maintenance business and only extract PCBs from transformers when there is a leakage or a functional problem. These companies will generally not take responsibility for the treatment/destruction/disposal of the PCBs after removal. There are other companies such as SED Inc., in the United States, who are in the business of extracting PCBs from transformers, taking over responsibility for disposing of the PCBs by government approved methods and then disposing of them.

4.5.1 Physical/Chemical Extraction Companies

		Company	Process Type
	-	SED Inc. Box 1306 Waukesha, Wisconsin	- physical/chemical extraction and ultimate disposal
	-	Transformer Service Inc. Concord, New Hampshire	- physical/chemical extraction
	-	Transformer Consultants P.O. Box 3575 Akron, Ohio	- physical/chemical extraction
*	-	D & D Group Smithville, Ontario	- physical/chemical extraction and treatment at D & D facility or transport to US for treatment
*	-	G.T. Wood Co. Ltd. 2552 Wharton Glen Mississauga, Ontario	- physical/chemical treatment and transport to US for treatment
	-	Kinetic Transport Systems P.O. Box 1037 Leduc, Alberta	- physical/chemical extraction and storage
	-	Canadian General Electric Service	- physical/chemical extraction

* transport to US for treatment is dependant on the pending approval by the US and Canadian governments to reopen the border to PCB transport.

All of these companies are approved to handle PCBs in Canada.

4.6 Bacterial Degradation of PCBs in Soils. Analysis of attempts at PCB degradation using soil bacteria showed that this degradation method was of limited potential due to long residence times, etc. A brief review of degradation by soil bacteria is included for completeness.

PCBs are extremely resistant to acid and base hydrolysis and oxidation. Their stability varies with the position of the chlorine substitutions but generally increasing with increasing chlorine content.

This structural relationship also holds for the resistance of PCBs to bacterial degradation. Mono- and dichloro-biphenyls have been readily biodegraded by activated sludge bacteria in a matter of days at low concentrations, higher concentrations taking longer. Trichlorobiphenyl degraded more slowly, tetrachlorophenyls were only slightly affected and pentachlorobiphenyls were unaffected.

This stability-structural relationship is borne out by the observation that Aroclors are fractionated in soils; the less chlorinated isomers disappearing first. PCB isomers may be categorized by degradation rate as follows:

Group A

Species containing two or less chlorine atoms, degrading rapidly with a half-life of eight days and 90% destruction in 15 days (Aroclor 1221, 1232).

Group B

Many tri- and tetrachlorobiphenyls. Half lives range up to 30 days, with 90% destruction in up to 60 days or more (Aroclor 1242, 1248 and components of 1254).

Group C

Penta - and greater substituted biphenyls. Half-lives are over a year. (Aroclor 1260 and components of 1254).

There is little quantitative data about the fate of biphenyls with seven, eight or nine chlorinated sites but they are considered much more persistent than Group C.

The slow destruction of PCBs in the environment may be outstripped by the evolution of micro-organisms able to degrade even the higher chlorinated PCBs. As a result, soils show limited potential for PCB destruction, although it may be developed, particularly by seeding with PCB adapted cultures.

References: (Farquhar and Sykes, 1978; Brooks, 1979; Iwata et al., 1974; Yagi and Sudo, 1980; Pat et al., 1980).

4.6.1 PCB Adapted Bacterial Cultures

Polybac Corporation
1251 South Cedar Crest Boulevard
Allentown, Pennsylvania 18103

Contact: Curtis S. McDowell, Vice President

Polybac Corporation has developed a series of mutant bacteria products which are capable of destroying chemicals in soil. One such mutant bacteria product is capable of degrading polychlorinated biphenyls i.e., PCBs.

The mutant bacteria products that Polybac Corporation manufactures are applied to the soil contaminated with PCBs in conjunction with an emulsifying agent. The soil is cultivated and kept moist for the duration of the degradation time required for PCBs.

Laboratory research reported in the open literature has demonstrated the biodegradability of several PCB mixtures by bacteria. For example, 99.8% destruction of 300 ppm Aroclor 1254 was achieved in 18 days. Polybac mutant bacteria have been shown to degrade a number of PCB isomers.

Polybac has been using mutant bacteria to biodegrade chemicals in soils for many years. Testing of the applicability of mutant bacteria to PCB degradation is quite recent and further testing is required to determine the efficiencies obtainable.

Bacterial degradation of PCBs is a process that works efficiently on less chlorinated biphenyls and offers a low cost alternative to excavation and landfill.

Reference: (Manufacturer's literature).

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